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MOTOR VEHICLE ASSEMBLY LINE TESTING

Final Report

Prepared by the

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for the

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MOTOR VEHICLE ASSEMBLY LINE TESTING

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MOTOR VEHICLE ASSEMBLY-LINE TESTI

PREFACE

This report was prepared by the Statistics Research Division of the Research Triangle Institute, Research Triangle Park, North Carolina under task number 2 of contract CPA 70-147. The work was sponsored by the Bureau of Abatement, National Air Pollution Control Administration (NAPCA), Durham, North Carolina. The purpose of the report is to provide NAPCA personnel with supporting information on Motor Vehicle Assembly-Line Testing as a means of making sure that the motor vehicle, as manufactured, meets emissions standards. Mr. R. E. Nelligan was the NAPCA project officer. At RTI, Dr. H. C. Sweeny was the Project Leader responsible for technical performance. Other key members of the project team consisted of Mr. B. H. Carpenter, Mr. S. B. White, and Dr. A. V. Rao.

I. INTRODUCTION

The problem to be addressed in this report concerns the control of emissions from motor vehicles and particularly the actions which may be taken before these motor vehicles are released by the manufacturers to the public. NAPCA exerts its main point of control, today, at the prototype stage, by issuing certificates for engine prototypes which pass certain criteria when subjected to a standard test procedure. The major requirements are on the level of carbon monoxide (CO) and hydrocarbons (HC) in the exhaust. The requirements on crankcase emissions seem to have been easily met. Regulations now under consideration for future application include control of nitrogen oxides (NO_x). The implication of today's controls is that engines may only be sold if they are certified.

Legislation has been introduced to provide for improved controls over motor vehicle emissions. Senate Bill S. 3466 amends Section 206 of the Clean Air Act to authorize the Secretary of Health, Education and Welfare to test new vehicles or engines being manufactured by a manufacturer to determine whether new motor vehicles and engines are in fact constructed in all material respects substantially the same as the certified vehicle or engine.

This study has been conducted to assemble meaningful information concerning motor vehicle assembly line testing for assisting policymakers in planning courses of action. Assembly line testing is herein projected as a program in quality control and assurance. As such, the program has two essential parts: the control and assurance program carried out by the manufacturers and the audit and monitoring function carried out by NAPCA. The information assembled herein relates to the planning, the development, and the implementation of both parts of the projected program.

II. BACKGROUND

A. Testing for Automobile Emissions Control

It seems axiomatic that if one wishes to reduce and control the emissions from motor vehicles, then those motor vehicles must first be designed and constructed to allow reduced emissions, and then they must be properly operated and maintained during their lives to retain their reduced pollution potential. It does not seem possible to affect any meaningful reductions in motor vehicle emissions unless the problem is tackled at each of three stages: design, manufacture, operation. Present regulations appear to recognize this simple fact and are indeed aimed at the first point of control: design.

As used here, the term "design" refers to the mechanical dimensions of all of the various parts of the engine, the specifications on the materials to be used in the manufacture of these parts, and the assembly instructions, settings, and tolerances to be used to assemble the parts into an operating engine. The design is represented by a prototype engine, in which the various parts are carefully made and assembled into a complete engine with settings carefully aligned as close to specified values as possible. This design (and prototype) is then translated into an engine to be mass produced, through the design and specification of the manufacturing process for each engine part, and the design and specification of the assembly and tuning of the engine.

B. Characteristics of Emissions Testing

In the testing for determination of certificability, the prototype is carefully tuned and maintained at the manufacturer's recommended settings. Thus, in a very real sense, the certificate test results on a prototype

should be considered as representative of the best emission performance which may be expected of that engine class. When the engines are mass produced (under the standards and methods which appear to be in use today) and subsequently operated, the emission levels should probably increase over the certified values, for a variety of reasons. First, there are no guarantees that the engine will be set and maintained at the manufacturer's recommended levels either at the time of sale or subsequently. Next, the parts of the engine are subject to a time (aging) effect, over and above the wear received through usage. Certification testing does involve the testing of vehicles up to 50,000 miles; this distance is put on them in a relatively short time. It would require some four years to accumulate an equivalent distance if the motor vehicle were in the hands of the average operating public. During this four year period, engine parts are environmentally stressed more than they are during the durability testing. For example, the engine goes through more cycles of temperature extremes (start-up, heat-up, shut-off, cool to ambient temperatures) and through more extreme temperature ranges during the four year period than during durability testing. Engine parts are more subject to chemical action (e.g., hydrocarbons and oxidants) over the four year period. Finally, there is probably a greater chance of cumulative damage of engine parts through the normal knocks received during routine maintenance over the four year period, in the hands of the motoring public, than is the case of an engine under a rigidly controlled durability test. Thus one should expect that the engine would have different characteristics over the 50,000 miles of actual and normal usage than over the 50,000 miles of durability testing; it is hypothesized that emission characteristics increase, not only with mileage, but additionally with age.

C. Assembly Line Testing

If motor vehicle emissions are to be kept under control, then in addition to certification testing, there is a need to make sure that the vehicle, as manufactured, meets standards of performance and finally that the vehicle, as operated, continues to meet the standards.

It was noted above that there may be a very real difference between a design concept (as represented by a prototype) and a mass produced engine. In general, the parts for the prototype are produced under more stringent control than are the parts for the mass produced engine, they are assembled with more care, and the prototypes may receive a degree of tuning rarely achieved in production engines. The operations involved in building mass produced engines have a degree of variability (over those used with prototypes) which should act to increase emissions. Just because a prototype has been certified, is no reason to expect that all individual engines, as produced, will behave as does the prototype; thus some type of control should probably be installed after a motor vehicle is manufactured but before delivery is made to the using public. This is the second important point of control; here the emphasis should be on insuring that the vehicle, as delivered, is capable of meeting the maximum allowable emission rate requirements.

D. State Testing

The third point of control is the state motor vehicle inspection of operating motor vehicles; this is the subject of a second study [1]* and will not be covered here except insofar as that aspect of control interacts with the other two discussed above. It seems reasonable to assume that one may not

*Numbers in square brackets refer to items in the list of references.

expect to successfully control motor vehicles in service to tighter regulations than those under which they were manufactured, unless one also requires modifications or additions to the vehicle. Thus, the amount of emissions from motor vehicles in service, which is the real and key element toward which all control functions should be directed, can not (without substantial mechanical changes) in all probability be reduced below the rates for the vehicle when new, and thus the new vehicle rates are a lower limit on future total emissions. This is the key to understanding the importance of the first two elements of control.

E. Relating Assembly Line and State Tests.

There is one practical point which should be considered in discussing the relationship between the second point of control (assembly line testing) and the third point of control (control while in use), and that is that there are strong advantages to requiring that the same test cycle be used in both of these control functions. It is likely that certification tests will continue to require detailed and involved testing procedures which include a large number of modes of operation. However, both the second and the third points of control will require shortened and abbreviated versions of the test cycle and there are many advantages to considering the same test for both of these points of control. If this were done, then the standards set by various states for in-use testing, would produce data comparable to that which would be produced by manufacturers during assembly line testing.

III. ASSEMBLY-LINE TESTING

A. Definition

Assembly line testing is projected for study as a quality control system requiring monitoring and audit.

B. NAPCA's Role

NAPCA's role in the projected assembly line testing program involves administration, with planning, development, implementation, and maintenance as key elements.

Planning is projected for study herein under the assumption that the automobile manufacturers, domestic and foreign, will conduct their own quality control and assurance work to determine that they are in compliance. NAPCA's staff will approve of test methods and procedures, set standards, and monitor the assembly lines by independently selected samples and tests, in addition to auditing test data from the manufacturer.

Development is discussed from the standpoint of effort and information required (1) to judge test methods and procedures especially short tests that may differ from certification tests, (2) to set standards, and (3) to implement their own monitoring system. The key technological problems that need to be solved under development are indicated and discussed.

Implementation is discussed from the standpoint of working out the sequence of steps necessary to establish assembly line testing as a functioning system.

Maintenance is considered from the standpoint of monitoring and auditing of the manufacturer's certification control and of assembly line control.

C. The Manufacturer's Role.

The automobile manufacturer's role is projected for study as a quality control system for a manufacturing process. Quality control methods are considered, including 100 percent versus sampling inspection. Costs of testing are developed assuming certain technological problems such as the development of a short test have been accomplished.

D. Methods and Standards.

The need for an Assembly Line Test.

Pending legislation (S.3466) links assembly line testing directly with certification testing. This link is established in subsection (c) (2): "If, based on such tests on a representative sample of such vehicles or engines (vehicles from the assembly line) the Secretary determines that such vehicles or engines do not conform with the regulations in effect on the date the certificate of conformity was issued, he may revoke such certificate and so notify the manufacturer. Such revocation shall apply in the case of any new motor vehicles or new motor vehicle engines manufactured after the date of such notification and until such time as the Secretary finds that vehicles and engines being manufactured by the manufacturer do conform to such regulations." The stated purpose of assembly line testing is to determine whether new motor vehicles are in fact being manufactured by a manufacturer in all material respects substantially the same as the test vehicle (that is, the vehicle tested for certification).

The certification test procedure is evolving into a 1370 second test, in which the automobile is subjected to a programmed cycle of operation with the speed, load, acceleration, or deceleration specified for each second. It now involves a seven-mode cycle. It also requires a "soaking" period of

twelve hours during which the automobile to be tested is kept in a controlled environment away from precipitation. Considerable effort has been made to make the test representative of driving practices. It has been developed to provide a carefully standardized measurement of the engine's emissions. The test results for each mode are weighted in calculating the final test result. After these computations, the test results are obtained in grams per mile.

This test is generally considered too expensive and too time consuming to apply directly to assembly line testing. For example, it is estimated that only one or two tests per hour could be made using this test. Under continuous sampling plans, one could not thus go one hundred percent inspection without slowing down the assembly lines by a factor of twenty or more. The federal test cycle would require driving the vehicle to some preassigned distance (4,000 miles) and then soaking the vehicles for a period of time until the temperature stabilized. This is obviously impossible on a one hundred percent sample test basis. Shorter versions of the test will have to be used to make assembly-line testing practical.

There are three areas in the federal test procedure which may be changed to shorten the time requirements of the test: the distance requirements on the vehicle may be reduced; the temperature soaking requirements of the test may be relaxed to allow a "hot-start", and the test cycle itself may be shortened. The short test must be shown to correlate closely with the certification test before it is to be officially approved for use in assembly line testing.

As a result of the work of manufacturers and independent laboratories, several short tests are now available for appraisal. For example, the procedures associated with the well-known Clayton KEY MODE cycle, [2], the New Jersey ACID cycle, [3], and the General Motors EXIT cycle, [4], all are candidates for

assembly line testing application. Their approval is contingent upon establishing good correlation with the Federal certification test. Data are being accumulated by the manufacturers to assess the correlation of short tests with the Federal test.

Method for Approval of an Assembly Line Test

A basic development problem for NAPCA is the problem of assessing and approving a short test. The approval of a short test requires the development and application of statistical techniques for cumulated data, for determining the relationship not only between the two tests, but also the relationship between the standards against which automobiles are to be accepted or rejected. For example, one question to be answered is: If a correlation coefficient of 0.8 or 0.9 is determined for the assembly line test compared to the Federal certification test, what can be said about the vehicle population passing the Federal test? The answer is that, for a given sampling procedure, standards need to be set for the assembly line test such that acceptance or rejection by these standards is equivalent to acceptance or rejection by the Federal test against its standards. What is involved is the iterative solution of equations relating the test results, the standards, and the correlation coefficients, to prepare sampling plan tables showing the necessary standards for various given number of samples and given correlation between tests.

The need for simultaneous consideration of standards can be shown by the following example, in which the statistical approach to development of the prescribed tables is formulated.

Consider only one emission rate, say, hydrocarbons (HC), and let HC_{max} define the largest allowable rate (gm. per mile) using the full Federal test cycle. The value of HC_{max} will have been selected to give the desired assurance of conformity for the Federal test. (Equal assurance is, of course, desired

for the application of the short test.) Let hc_{max} denote a critical value selected for the short test. (Short test results will be denoted by lower case letters, full federal test results will be denoted by capital letters.) A short test is conducted on a vehicle and the value of x is observed. Let X be the corresponding federal test result on this vehicle. There are then four possible results:

$x < hc_{max}$, $X < HC_{max}$: (vehicle good by federal test, short test results in agreement)

$x < hc_{max}$, $X > HC_{max}$: (vehicle actually out of specs, but short test misclassifies it as being in specs.)

$x > hc_{max}$, $X < HC_{max}$: (vehicle actually in specs, but classed as being out of specs by the short test)

$X > hc_{max}$, $X > HC_{max}$: (vehicle actually out of specs and so classified by short test)

The effect of perfect correlation between the standard test and a shortened version is to eliminate the misclassification errors, given that the relationship between the two tests has been properly estimated. The problem, in these terms, is to select (hc_{max}) to give as close to the desired assurance as possible. In any given situation, one can derive the degree of assurance in terms of hc_{max} and the sampling rates. For example, suppose the short test had been so developed that the test was unbiased, but that the test exhibited a variability of σ^2. Then under the normality assumption, the probability that a vehicle is rejected, when the true emission rate is X, is given by

$$P(x > hc_{max}|X) = 1-F\left(\frac{hc_{max} - X}{\sigma}\right) ,$$

and one may calculate this probability of rejecting a single vehicle when the true emission rate is X. The operating characteristics of the sampling plan are determined from a range of such values; one may evaluate the assurance

given by different values of hc_{max}, and eventually find the value of hc_{max} and the plan which will yield the desired assurance.

Note that the effect of the correlation between the long (Federal) and the short test is reflected through the particular plan selected; thus one cannot, in general, make statements about the correlation coefficients required (or the effects of various specified coefficients) without also specifying the plan used for control.

E. Green Engine Testing.

Consider the problem of testing green engines from the assembly line. The green engine test result is omitted in certification testing. What, then, is known about the relationship between a "zero" mile (green engine) test, and testing when the engine stabilizes?

It has been hypothesized that tests on green engines may result in values which are much too high, as the engines may contain paint and other chemicals such as solvents which must be "burned-off". Supposedly, the engine "stabilizes" at some point, and it is assumed that such stabilization occurs before 4,000 miles.

A test program currently being run by DMVPC offers some information on this question. In this program, 36 new vehicles were picked up from the ends of assembly lines (12 of them were Ford Galaxies, 12 were Chevrolet Impalas, and 12 were Plymouth Fury III's). They were given duplicate certification tests at the DMVPC labs. Half of the automobiles in the sample for each make were then driven for 2000 miles and the other half were driven for 4000 miles, and then duplicate tests were again run on each vehicle. The test is currently being conducted as this report is being written, so that not all of the data

are available for consideration; the facts given below seem to emerge from the data at hand.

Hydrocarbons

The available test results with regard to HC are summarized below; the two entries in each cell are duplicate test results, the first run on the automobile as received, the second, after adjustment of the engine.

	Green Engine	2000 m.	4000 m.
Chevrolet	1.49/1.39	--- / ---	--- / ---
Ford	2.44/1.90	1.85/1.80	2.59/2.54
Plymouth	1.85/1.57	1.84/1.60	--- / ---

Note the following points:

a) All averages of second test results are less than the corresponding averages of the first test results; the difference at each mileage is the result of tune-up.

b) The two results for the green engine show a large drop between the first and second test for Ford and Plymouth (significant) but not for Chevrolet.

c) For Fords (for which almost complete data are available), the 2000 mile results equaled the second (tuned-up) result on the green engine; the 4000 mile result was significantly greater than the 2000 mile result. On the other hand, the 2000 mile results for Plymouth are almost exact duplicates of the pair of results on the green engine.

Carbon Monoxide

The average results for CO, for these same vehicles, are given below:

	Green Engine	2000 m.	4000 m
Chevrolet	23.87/21.36	--- / ---	--- / ---
Ford	22.58/18.01	19.22/17.54	19.65/18.31
Plymouth	29.75/23.46	15.77/14.61	--- / ---

Note that:

a) Again, all second test averages are less than the corresponding first test averages.

b) The result for Ford appeared to be "stabilized" by the second test on the green engine, whereas the Plymouth results showed marked change at 2000 miles over green engine results.

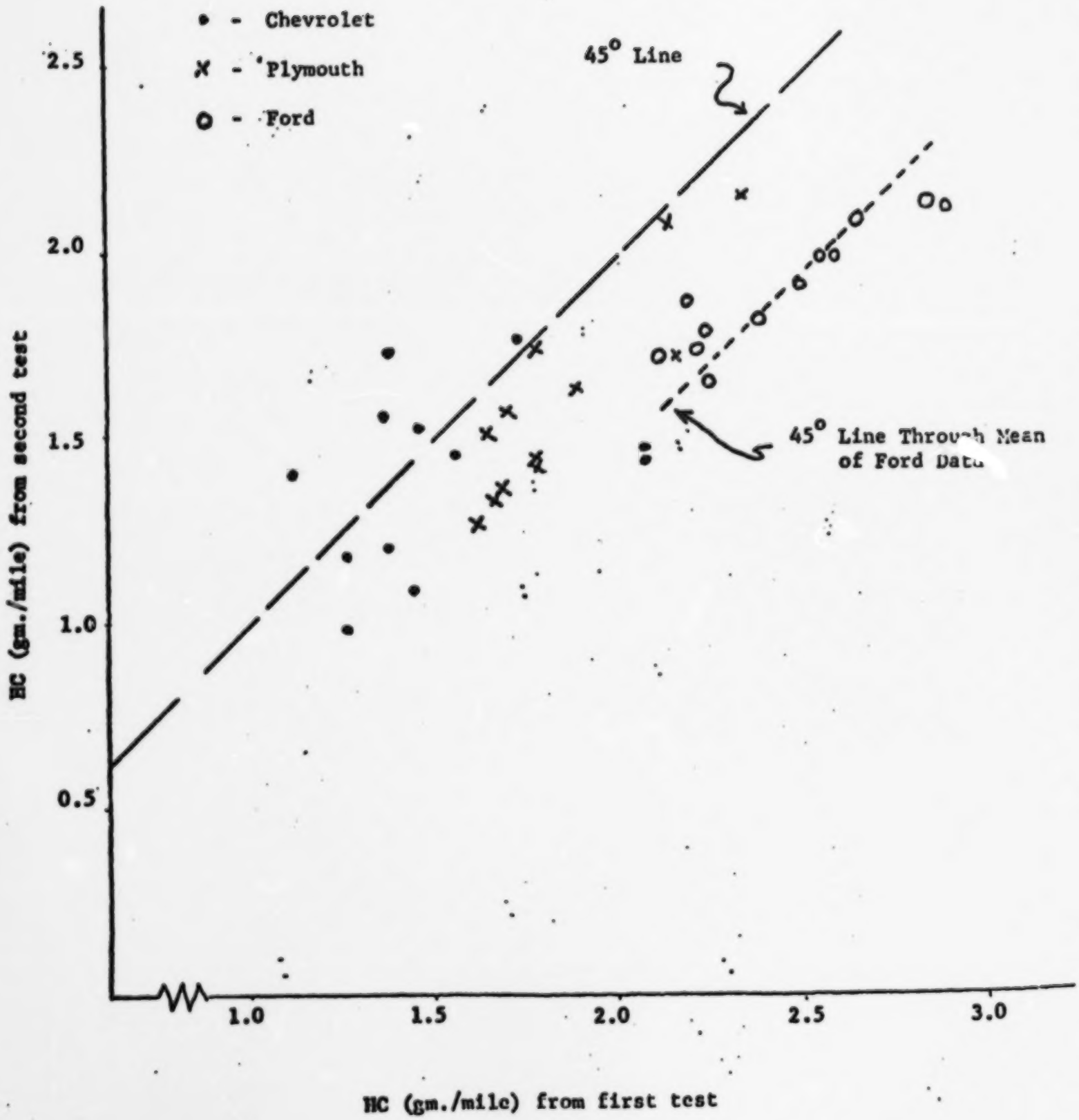
Several conclusions may be drawn from these data. First, the initial test results on green engines, although higher than the second test results, do not show excessive variability, which indicates that tests on a green engine may be entirely practical for control purposes. The second fact which emerges is the difference in behavior, between makes of vehicles, as distance is accumulated. This points out, since this appears to be the limit of available data within NAPCA, the need to define further and clarify the emission relationships over the various stages in the life of vehicles.

Attention may be focused on the pairs of results for HC for green engines. These pairs are plotted in Figure III-1, with closed circles indicating Impalas, crosses indicating Plymouths, and open circles denoting Fords. Consider the results:

a) Fords gave the highest average values of HC.

b) The average improvement due to engine adjustment between the first and

Figure III-1
Plot of HC Results on Green Engines; 36 Car NAPCA Test.



second test on Fords was 0.54 gm/mile, as reflected by the distance of the open circles from the 45° line (dashed). The average improvement for Plymouths was 0.28 and for Chevrolets was 0.10. This might imply that Chevrolets are more carefully factory tuned than are Fords or Plymouths.

c) On the other hand, the very low amount of scatter of Fords about the 45° line in Figure III-1, as contrasted with the scatter exhibited by Chevrolets, might imply that Fords are more easily tunable than are Chevrolets.

In summary, values for Chevrolets did not change much, on the average, with engine adjustment, but the individual results varied quite a bit from test to test. Ford results changed by about 25% from the first to the second tests; the car-to-car variation was about equal to that for Chevrolets, but the individual vehicles exhibited a greater degree of stability from test to test.

This whole topic may best be summarized by noting that the picture at this point is somewhat confused; hopefully it will be somewhat cleared up when the remaining data are added to those presented above and the total data analyzed. At this point in time, the authors do not know how the emission characteristics of engines change over time, with any degree of certainty.

F. Relationship between a green engine test result and a test result when the engine is stabilized at 4000 miles.

As indicated in III-E, the green engine HC test result on Fords is significantly lower than the 4000-mile test result. Comparing the results for tuned-up engines, the green engines averaged 1.90 gm/mi., while the same engines averaged 2.54 gm/mi. at 4000 miles. On the other hand, the CO

test results are essentially the same, 18.01 for green engines versus 18.31 at 4000 miles. Obviously, more data will be required to obtain a valid equivalence factor relating green engine performance to 4000 mile performance.

Since this relationship cannot now be established, it is proposed that during development of the assembly line test program, a study of the equivalence factor be made, using statistically-designed experiments. This study would utilize the percent 36-car study by DMVPC as a base, and build upon the data to be obtained. For example, data to date from the 36-car study show an equivalence factor of unity between green engine and 2000-mile test results for one type of automobile. That is, the ratios 2000-mile test result/green engine result, for Ford HC results are 1.80/1.90 for HC and 17.54/18.01 for CO, on the average. These ratios are not significantly different from unity. At 4000 miles, the ratio for CO held firm for these automobiles; but the ratio for HC increased significantly (2.54/1.90). The green engine tests on these automobiles are not out-of-trend.

If the green-engine test result can be utilized in the trend analysis of certification data, then the reliability of the equivalence factor can be improved by making more frequent observations of emissions in the certification durability test. Doing so would not increase the number of vehicles to be tested beyond the number now required for certification.

The suggested study should include measurement of the vehicle to vehicle variation within a type of automobile. Perhaps the best way to obtain this information is to use some of the earliest data from the initial assembly line tests.

The study should investigate:

1) The possibility of including green engine results in certification tests,

2) the possibility of establishing an equivalence factor from these tests,

3) the possibility of using the correlation between short tests and the variance of test results from certification tests to establish a minimum testing program for relating 0-mile and 4000-mile test results.

This study will require an estimated one man year of statistical effort, plus a corresponding year of effort in running tests, involving NAPCA and sponsors of short tests. It should be pointed out that this study could include the previously mentioned effort required under III-D.

As part of this current study, the investigators were asked to determine the numbers of vehicles which must be tested to establish equivalence factors for emissions from green engines and from engines driven to 4000 miles. Many of the factors which go into this have been discussed above; the most important type of data needed for this determination is the variation of results from tests such as the 36 car test currently underway. The determination can not be made until all of the data from that test becomes available.

G. Requirements for an Assembly Line Test.

Next, consider the types of tests which could be used with assembly line testing; some of the requirements on acceptable test procedures are:

a) That the individual test can be completed in a satisfactorily short time. In calculating costs (Chapter VI), an overall time requirement of 4 minutes was used, as this seemed to be a time interval which could be achieved with available technology. Some such time will be required if this program is to succeed.

b) That the test results correlate to a satisfactorily high degree with the federal certification test. This level of correlation should be somewhat greater than 0.85--preferably over 0.90. The effect of poor

correlation is twofold: it first reduces the power of the assembly line test to discriminate poor quality and also causes the standard to be set lower than it would be if the correlation is sufficiently high.

c) That the test would also be suitable for use by the various states in inspection programs on in-use vehicles.

d) That the test results could supply diagnostic information on the possible causes of high emission rates.

H. Conclusions.

1) The available information on EXIT, KEY MODE, and ACID was reviewed in an attempt to allow each of these to be evaluated in relation to the four items given above. The data were too scanty for most of the items to provide credible conclusions for selection purposes.

The development of an acceptable short test procedure which will correlate with the new Federal test (infinite mode) procedure is of the highest priority in the development of this program. The importance of such a test is easily seen from the economics involved (see Chapter VI).

2) After a short test has been developed and correlated with the Federal test cycle, the problem remains of selecting the critical values against which acceptance or rejection of short test results on single vehicles will be based. Such critical values should be selected to give a desired operating characteristic for the inspection program including the effects of uncertainty due to the relation between the short test result and the Federal test result.

IV. ASSEMBLY LINE TESTING BY MANUFACTURERS

A. Definition and Purpose

Assembly line testing is projected as a quality control function carried out by the manufacturer to assure himself that automobiles from his assembly lines meet prescribed standards for control of emissions. An additional aspect of assembly line testing, for the manufacturer, is to provide data to NAPCA showing conformance with emissions control regulations.

Assembly line testing is assumed to involve the application of a suitable short test, using equipment and facilities provided by the manufacturer. The test equipment may be subject to calibration, or checks on calibration, by NAPCA personnel.

Thus in this section, it is assumed that a suitable test has been developed, and is to be implemented.

The purpose of assembly line testing is to assure that vehicles, as delivered to dealers for sale to the public, are assembled and tuned properly, as gauged by the fact that they meet a set of minimum requirements. To achieve this purpose, motor vehicles would be sampled and tested at or shortly after the end of the assembly line in domestic plants.

B. Types of Inspection.

There are essentially two alternatives--100 percent inspection, or sampling inspection.

The two alternatives, use of 100 percent inspection or use of sampling inspection differ in what can be said about the automobiles under inspection. With 100 percent inspection, one can state that a certain identified proportion of the automobiles failed to pass the standards. With sampling inspection,

one can state with specified confidence that not more than a certain percent of the automobiles would fail the test. When the confidence level of this statement is to be high, approaching 95 percent for example, the sampling plan will require either a greater amount of testing, that is a larger sample size, or a better lot of cars must be submitted for inspection. For example, suppose that two percent of a manufacturer's automobiles fail to meet prescribed standards. They are inspected under a sampling inspection plan that assures, with 95 percent confidence, that not more than five percent of an accepted lot would fail to meet standards. Note that the quality of the manufactured automobiles is better than the quality guaranteed by the plan: 2 percent vs five percent. Nevertheless, if the manufacturer now inspects 55 cars per lot, he will accept only 50 percent of his lots! If he inspects 100 cars per lot, he will accept 75 percent of the lots. Thus there are many different sampling inspection plans, that differ in number inspected, in the confidence level of assurance, in the quality guaranteed, and in the percent of lots accepted. There are essentially two types of sampling inspection plans--continuous sampling plans and lot sampling plans. Continuous sampling plans apply to situations like assembly lines where a continuous succession of automobiles are to be assessed as they leave the line. Lot sampling plans apply to situations where continually produced automobiles are collected into specified groups or lots, and sampled and judged as a group.

C. Standard for Sampling Inspection

It should be clear that sampling plans do not provide infallible judgements. In some individual circumstances, lots will be rejected which should be accepted, and vice versa. However, one may calculate the fraction of lots of a given quality level which will be accepted; the plot of this fraction

against the quality level of the lot is called the Operating Characteristic (OC) Curve for the plan.

To reiterate, the OC curve gives the probability of acceptance by sampling inspection versus the proportion of out-of-specification vehicles actually present in a lot or in a continuous run of vehicles submitted for inspection.

Since all types of sampling plans may be devised to have approximately the same OC curves, it is important to identify the OC curve desired for the sampling plan and thus establish a criterion for development and comparison of alternative inspection plans. This is done by considering what the sampling plan is to guarantee. For example, Figure IV-1 shows an OC curve for a plan which guarantees, with ninety percent confidence, that no more than five percent of the automobiles in accepted lots will be "out-of-specification."*

Figure IV-1 helps identify the effect of submitted quality and sample size on the performance of sampling inspection plans. To achieve the guarantee, only a certain proportion of good lots of automobiles will be accepted under sampling inspections. For example, lots containing three percent "out-of-specification" will be accepted only 37 percent of the time using a sample of 50. Such lots will be accepted 55 percent of the time using a sample of 100.

By inspecting all cars in the lots that fial to pass sampling inspection, it is possible to guarantee that not more than five percent, for example, of the outgoing automobiles fail to pass standards. Thus, regardless of the quality being presented for inspection, the outgoing quality will be no greater

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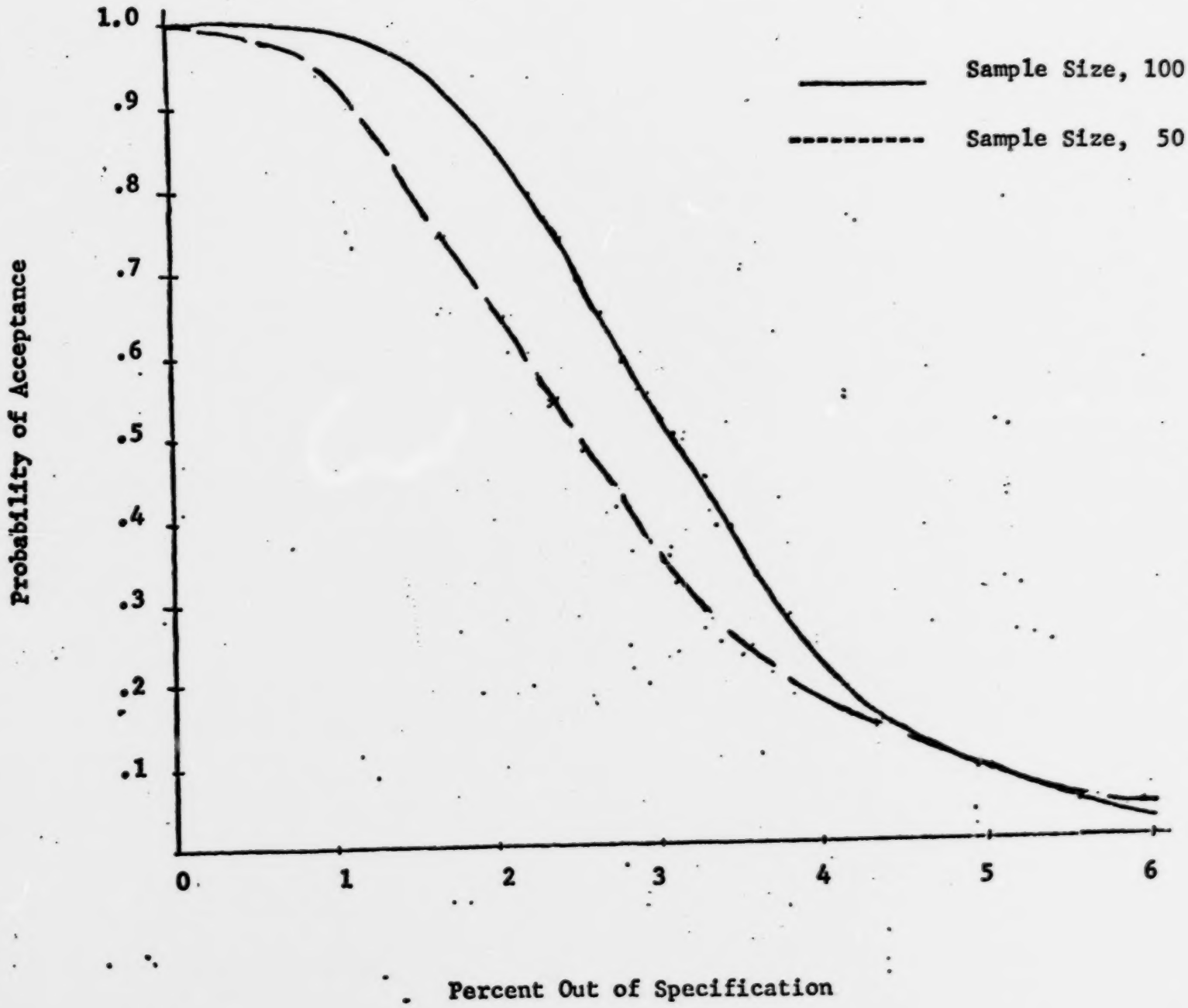
*This choice of guarantee and confidence was selected at this time to provide a reasonable basis for subsequent discussion and comparison of plans. It is not necessarily the recommended standard for assembly line testing.

Figure IV-1
Operating Characteristic Curve for Sampling Inspection That Guarantees Not More Than 5 Percent Defective Automobiles With 90 Percent Confidonce.



than five percent "out-of-specification." The outgoing quality limit (AOQL) is five percent. Figure IV-2 shows, as an example, a plot of the average outgoing quality (AOQ) against the quality submitted for inspection, for two sampling inspection plans which will be considered further under Chapter VI, Costs. This is the AOQ curve.

The basic standard for a sampling inspection is that it must provide an acceptable outgoing quality. For example, a plan must limit five percent, maximum, the percent of automobiles that fail to meet emission standards.

The OC curve and the AOQ curve may then be used to compare and appraise any proposed sampling inspection plan.

D. Requirements Imposed By the Standard for Inspection Plans.

As developed herein, the Standard for Inspection Plans requires that the manufacturer set up his plan so that, regardless of how many "out-of-specification" automobiles he makes, those put into the market will contain no more than five percent "out-of-specification." As previously explained, the choice of five percent is made to provide an example for discussion. While this choice seems reasonable from many standpoints, it is not to be construed as a set standard. Rather, it permits practical consideration of questions relevant to the development and cost estimation of inspection programs.

Number of Vehicles to be Tested

The questions to be considered here are for example:

"Under a proportional sampling procedure, how many vehicles need to be tested to assure that 95 percent of the vehicles pass the standards, with 95 percent confidence? With 90, 75, and 50 percent confidence? How could the taking of samples be scheduled?"

The manufacturer cannot really determine how many vehicles need to be tested without considering the quality of his automobiles as submitted for inspection. As the percent out-of-specification goes up in submitted automobiles, more tests will be required to permit acceptance of 95 percent of the lots. Also, as the confidence level of assurance goes up from 50 to 75, 90 and 95, the number of tests required to permit acceptance of 95 percent of the lots increases.

Table IV-1 shows the percent "out-of-specifications" in automobiles submitted for inspection required if 95 percent of the submitted lots are to be assured for not more than five percent "out-of-specifications." The table shows what can be done with sample sizes of 5, 10, ...100. It shows the effect of different confidence levels on the percent out-of-specification that will be accepted.

Table IV-1 is based upon inspection by variables, that is, the actual numerical values of the test results are used in determining whether to accept or to reject the lot of like automobiles. This type of plan is considered here, rather than one based solely on acceptance number, because the tests provide the actual results instead of merely a "pass or fail" classification. This makes the "variables sampling plan" feasible.

Variables Sampling Plan vs Rejection Number Scheme

Variables sampling plans have the advantage of usually resulting in considerable savings in sample size for comparable assurance of the correctness of decisions in checking the single quality characteristics or for the same sample size greater assurance is obtained using variables plans. Attribute sampling plans usually employ a rejection number to determine whether a lot has passed or failed. They have the advantage of greater simplicity by being

TABLE IV-1

Lot Sampling Plans, Showing the Per Cent "Out-of-Specification" in Submitted Lots Required in Order that 95 Per Cent of Submitted Lots Will Be Assured For Not More Than Five Per Cent "Out-of-Specifications" at Stated Confidence Level.

Sample Size	Confidence Level, Percent			
	50	75	90	95
5	0.25	0.01	0.00	0.00
10	0.70	0.15	0.02	0.00
15	1.06	0.37	0.09	0.03
20	1.34	0.58	0.21	0.09
25	1.57	0.77	0.34	0.18
30	1.75	0.95	0.47	0.28
35	1.91	1.10	0.59	0.38
40	2.04	1.24	0.71	0.48
45	2.16	1.36	0.82	0.58
50	2.26	1.47	0.93	0.67
55	2.35	1.57	1.02	0.76
60	2.43	1.66	1.11	0.85
65	2.51	1.75	1.20	0.93
70	2.57	1.82	1.28	1.00
75	2.64	1.90	1.35	1.07
80	2.69	1.96	1.42	1.14
85	2.75	2.03	1.48	1.21
90	2.80	2.09	1.55	1.27
95	2.84	2.14	1.61	1.33
100	2.89	2.19	1.66	1.38

applicable to either single or multiple quality characteristics and by requiring no knowledge about the distribution of the continuous measurements of any of the quality characteristics. Note that the use of a variables sampling plan requires the accumulation of some knowledge about the distribution of the quality measurement. Only the variables sampling plan is considered herein, because the use of conventional attribute plans affords too little protection against the placing of rejectable automobiles in consumers' possession.

The results given in Table IV-1 refer in general to large lot sizes. It can be shown, that if small sized lots are defined for control and if one achieves the same degree of protection as implied in Table IV-1, then the manufacturer will have to inspect almost 100% of every lot.

Selection of Samples.

Regardless of whether a continuous sampling plan or a lot sampling plan is employed, the prescribed number of samples is to be selected in such a manner that each automobile eligible for selection has an equal opportunity to be chosen. For example, in continuous sampling when one out of every three like automobiles is to be inspected, the particular one to be chosen is determined by a table of random numbers or a computerized random number generation program, or other means that selects a random sample for inspection. As another example, a lot could be designated as the number of like cars assembled in the first 18 hours of daily production plus those assembled the last two hours of the previous day. This assumes two 10-hour shifts per day. It would thus tend to permit testing of most of the daily production before the end of the second shift, and eliminate hold-over of the major portion of assembled cars. Given the number to be assembled, the prescribed number of vehicles for testing would be selected as a random sample of these

numbers. Each car of a given type would be numbered successively, and those whose numbers corresponded to the selected sample numbers would be subjected to testing.

What Can Be Said if Ten Cars Per Shift Were Inspected?

The outgoing quality can be assessed using ten samples per shift. As indicated in Table IV-1, a sample of ten from a lot of like automobiles will assure with 50 percent confidence 95 percent of all lots submitted, provided the lots contain not more than 0.25 percent "out-of-specification" cars! For any higher percent confidence, the submitted automobiles must essentially all meet the standards if 95 percent of the lots are to be passed. Thus, reading from the second row of Table IV-1, to assure 95 percent of the lots with 75 percent confidence, the percent out-of-specification in submitted lots must be not more than 0.15. Continuing across the row in the Table, to pass 95 percent of the lots with 90 and 95 percent confidence, the percent out-of-specification must be 0.00.

However, ten samples per shift will not be the total testing load required by any sampling plan, even if only ten samples per shift are taken for the initial assessment of each lot. The reason for this is that any rejected lot is to be subjected to 100 percent testing, in order to maintain prescribed limits on the percent out-of-specification in outgoing automobiles. All remaining automobiles in a rejected lot must therefore be tested. The total testing required will depend on the percent of lots rejected. The percent rejected will depend of course, on how many out-of-specification cars there are in submitted lots. For example, Table IV-2 shows the maximum percent out-of-specification that submitted lots can contain if various specified

proportions of the lots are to be accepted using a sample size of 10 per shift.

E. An Example of an Assembly Line Testing Program.

Comments on Existing Sampling Plans.

This section is concerned with statistical sampling techniques and procedures which may be employed in evaluating emission quality of automobiles coming from a continuous assembly line. Existing sampling plans include MIL-STD-105A and MIL-STD-414 [5]. The latter would utilize the actual measurements obtained in tests rather than judging the automobiles merely as passed or rejected. They are therefore more relevant for assembly line testing. They provide more information for monitoring a testing system; they tend to be more efficient in the sense of requiring less testing than pass-fail types of plans.

Plans included in MIL-STD-414 were developed to accept a specified average quality ninety percent of the time. One of these plans requires a sample size of 3 for small lots, and uses an acceptance criterion, K, of 1.12. The plan will indeed accept 90 percent of the lots having at most 2.5 percent out-of-specification. However, this plan differs substantially from those of Tables IV-1 and IV-2, which guarantee not more than 5 percent "out-of-specification" at 90 percent confidence. The MIL-414 plan will guarantee that not more than 49 percent of an accepted lot is "out-of-specification." In other words, if lots of assembled automobiles are submitted containing 49 percent "out-of-specification," these lots will be accepted ten percent of the time by MIL-414 plans! This level of protection of the consumer is considered unsatisfactory for automobile assembly line testing.

TABLE IV-2

Submitted Lot Quality versus Proportion of Lots Accepted Using a Sample-Size of 10 and Assuring Not More than Five Percent "Out-of-Specification" at Prescribed Confidence Level

Confidence Level, %	Proportion of Lots Accepted						
	0.05	0.10	0.15	0.20	0.25	0.30	0.35
50	20.18	15.53	12.82	10.92	9.46	8.27	7.27
75	13.45	9.51	7.38	5.96	4.92	4.12	3.47
90	7.71	4.82	3.41	2.55	1.96	1.54	1.22
95	4.73	2.63	1.71	1.19	0.86	0.63	0.47

Confidence Level, %	Proportion of Lots Accepted					
	0.40	0.45	0.50	0.55	0.60	0.65
50	6.42	5.67	5.00	4.39	3.84	3.33
75	2.94	2.49	2.11	1.77	1.48	1.23
90	0.97	0.77	0.62	0.49	0.38	0.29
95	0.36	0.27	0.20	0.15	0.11	0.08

Confidence Level, %	Proportion of Lots Accepted					
	0.70	0.75	0.80	0.85	0.90	0.95
50	2.85	2.40	1.97	1.56	1.14	0.70
75	1.00	0.79	0.61	0.44	0.29	0.15
90	0.22	0.16	0.11	0.07	0.04	0.02
95	0.06	0.04	0.02	0.01	0.01	0.00

The standards considered for automobile assembly line testing (III-D) require more stringent plans than those presented in the major MIL standards.

The Continuous Sampling Plan.

For sampling inspection of domestic production, it is recommended that a continuous sampling plan be used by automobile manufacturers. These plans reward manufacturers, through reduced sampling, for high quality, and afford a given degree of protection to NAPCA and to the public. In using such plans, it is assumed that each car that fails the test will be corrected--in one way or another--before it is shipped, and that subsequent retests of such automobiles are not considered as part of the sampled fraction.

As envisioned here, the production stream of vehicles from an assembly line would be subjected to a continuous sampling plan in which every r^{th} vehicle would be selected (with a randomizing device to avoid the chance that cyclical production schedules might introduce bias into the sampling) and tested using a short form of the emission rate test. If either the measured HC or CO exceeds standard values, then every vehicle would be inspected until k successive ones were found without a single defective vehicle. At that time, sampling would revert to every r^{th} vehicle.

When quality is "bad," almost every vehicle would be tested and corrected. When quality is good, only a few would be tested.

Statistical procedures (referred to as Continuous Sampling Plans or CSP) for sampling a continuous production process were first proposed by Dodge [6] almost thirty years ago. The most important feature of continuous sampling is the elimination of "lots." Whereas in lot acceptance sampling a decision is made regarding acceptance or rejection of the lot, in continuous sampling a decision is made relative to the frequency of testing on

subsequent production units. Although the above may be oversimplification, it indicates the underlying difference between lot acceptance and continuous sampling.

There are two basic types of continuous sampling plans: single-level and multi-level. In the single-level plan, sampling is confined to a specified frequency, f. In the multi-level plan, sampling frequency is varied according to the quality of the product being produced. These will be discussed in detail in the following paragraphs.

Single-Level Continuous Sampling

The single-level type of continuous sampling was first introduced by Dodge [6] and is referred to in the literature as CSP-1. This plan begins by requiring 100% inspection of the product until a specified number, i, of consecutive defect-free units are found. Immediately, the 100% inspection is discontinued and a randomly selected fraction, f, of the succeeding units is inspected. Sampling continues at this prescribed level until a defective unit is found, at which time the 100% inspection is invoked and continues until the requirement of i successive defect-free units is again achieved. This plan may be applied to individual defects and also to classes of defects.

Values of i and f determine a specific CSP-1 plan. Each CSP-1 plan has certain operating characteristics which reflect the amount of protection offered by the plan. There is associated with each CSP-1 plan an over-all AOQL (average outgoing quality limit). The AOQL is defined as the worst average outgoing quality that will result from the plan over a long-run period regardless of the quality of the product being produced. Specific values of i and f will yield a value of AOQL. However, different

combinations of i and f will yield the same AOQL value. Dodge prepared a chart giving the i and f combinations that will yield a given AOQL. In addition to the AOQL there are other characteristics which describe a specific CSP-1 plan. These are:

$$u = \frac{1-q'^{i}}{p'q'^{i}} = \text{the average number of units inspected after finding a defect}$$

$$v = \frac{1}{fp'} = \text{the average number of units passed by the sampling plan before a defect is found}$$

$$AFI = \frac{u+fv}{u+v} = \text{average fraction inspected}$$

$$P_a = \frac{v}{u+v} = \text{average fraction of produced units passed under the sampling plan}$$

where

p' = process average (in fraction defective)

q' = 1-p'

i = number of consecutive defect-free units necessary to be found under 100% inspection before going to sampling

f = fraction of units inspected under sampling plan.

When P_a is plotted as a function of p', the result is an Operating Characteristic curve. Whereas the OC curve in lot acceptance sampling gives the percentage of lots that would be passed under the plan, the OC curve for a continuous sampling plan gives the fraction of submitted units passed under sampling inspection.

The average outgoing quality (AOQ) curve may be obtained by plotting AOQ = p'[1-(AFI)] versus p'. This curve will have a maximum which is referred to as the average outgoing quality limit (AOQL).

Multi-Level Continuous Sampling

Multi-level continuous sampling plans were originally proposed by Lieberman and Solomon [7] and provide a procedure whereby the fraction inspected is increased or decreased by steps or levels depending upon the quality of the units tested. By allowing several levels of sampling inspection, abrupt changes in inspection are avoided (i.e., in CSP-1 plans the fraction inspected goes from f to 100% inspection in one step and vice versa). Multi-level plans begin with 100% inspection, and go to a fraction f as soon as a run of i defect-free units has been found. While under sampling inspection at rate f, if an additional i consecutive units are found to be nondefective, then the sampling rate is lowered to f^2. If under this sampling rate, another i consecutive units are again found free of defects, then the fraction inspected is further reduced to f^3. This may continue through the several levels as specified by the plan. If a defective unit is found under sampling inspection, the fraction inspected is immediately changed to the next higher level. For example, if a defect is found while using f^3 as the fraction to be inspected, a change is made immediately to the fraction f^2. The effect of multi-level plans is to lighten the inspection load when production is running at a low fraction of defectives and to increase the load when production is running at a high fraction of defectives. This is accomplished, however, without abrupt changes in the inspection load.

The plan just described is very similar to that outlined in the Department of Defense Handbook, H-106 entitled, "Multi-Level Continuous Sampling Procedures and Tables for Inspection by Attributes." H-106 incorporates, however, a special procedure for inspecting the next four units immediately following the discovery of a defect to determine whether sampling should continue at the same level or revert to a higher level. This provides a means

for differentiating between the random occurrence of a defective unit (with overall quality level still acceptable) and inferior or spotty quality.

Values of i, f, and k determine a specific multi-level plan. Values of i and f are as defined in CSP-1 plans and k is the number of levels to be used in the plan. For example, if k = 3, then sampling will be conducted at the levels f, f^2 and f^3. The desired sampling plan is one giving the specified AOQL and the plan which provides assurance that the smaller sampling levels will be reached and used sufficiently to provide a substantial savings in the cost of inspection or testing.

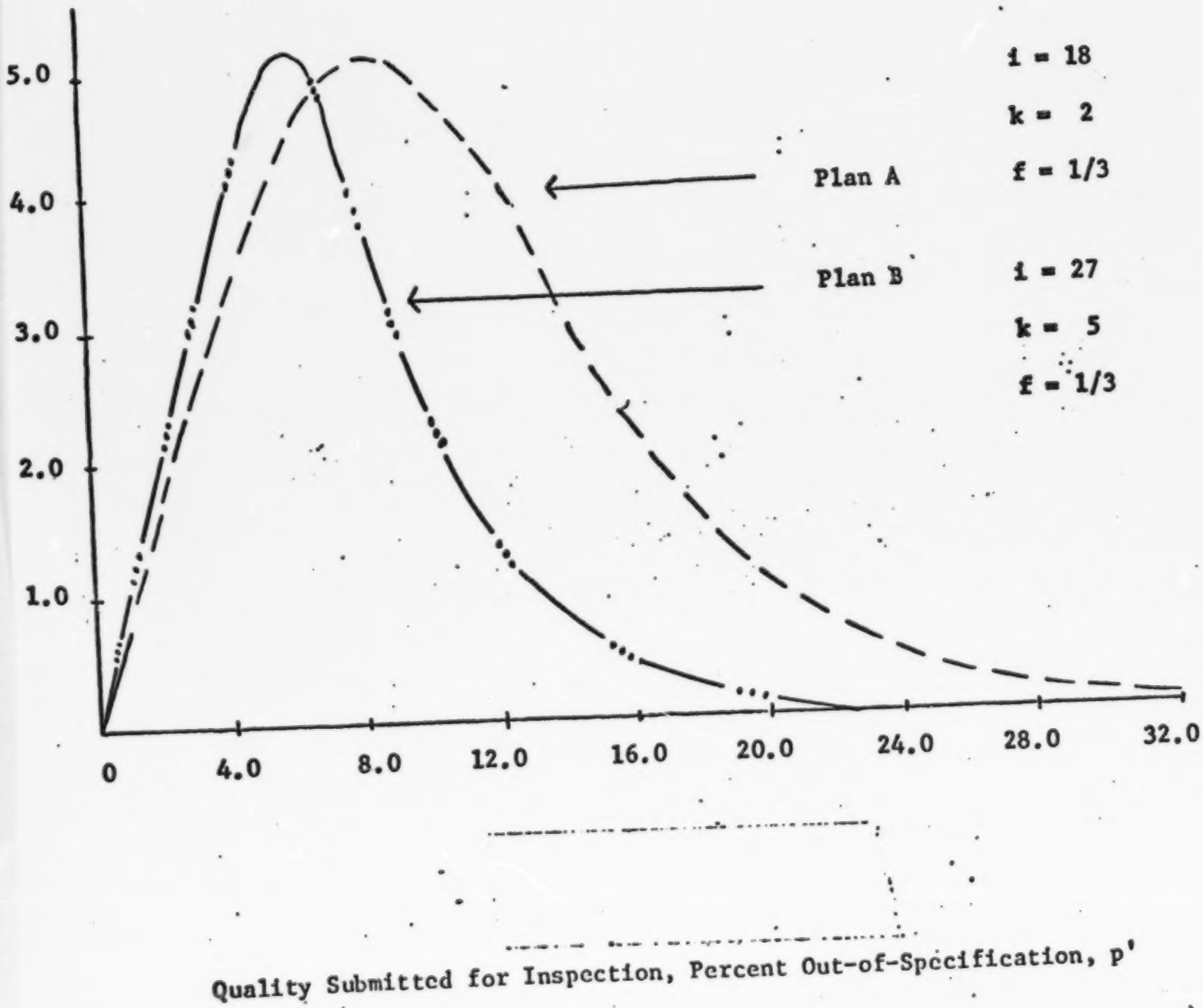
Only an overall description of multi-level continuous sampling plan has been presented. The Department of Defense Handbook, H-106, presents in detail the mechanics of implementation. In addition, various plans are presented in that document covering a wide range of applications, and other plans could be easily developed if desired.

In order to illustrate the protection afforded (to the consumer) by multi-level continuous sampling plans, two of the plans given in H-106 are presented below and their characteristics are compared:

Plan A:	Plan B:
i = 18	i = 27
k = 2	k = 5
f = 1/3	f = 1/3

Figure IV-2 shows a plot of the average outgoing quality (AOQ), against incoming quality, for the two plans. Note that for each plan the AOQ reaches a maximum of 5%; this maximum value is known as the AOQL (i.e., AOQL=5%). This says that both plans will guarantee that regardless of the quality, p', being presented for inspection, the outgoing quality will be no greater than 5%. The actual outgoing quality depends on the incoming quality, p'. These

Figure IV-2
Average Outgoing Quality Curves
(In Percent Defective)



curves are based on the assumption that all "defective" automobiles found are "fixed" before release for sale. If the incoming quality, p', is less than 7%, then plan A has a lower average outgoing quality. On the other hand, for p' > 7%, plan B has a lower AOQ. The important thing to note from Figure IV-2 is the fact that both plans A and B will insure that outgoing quality will not exceed 5% defective.

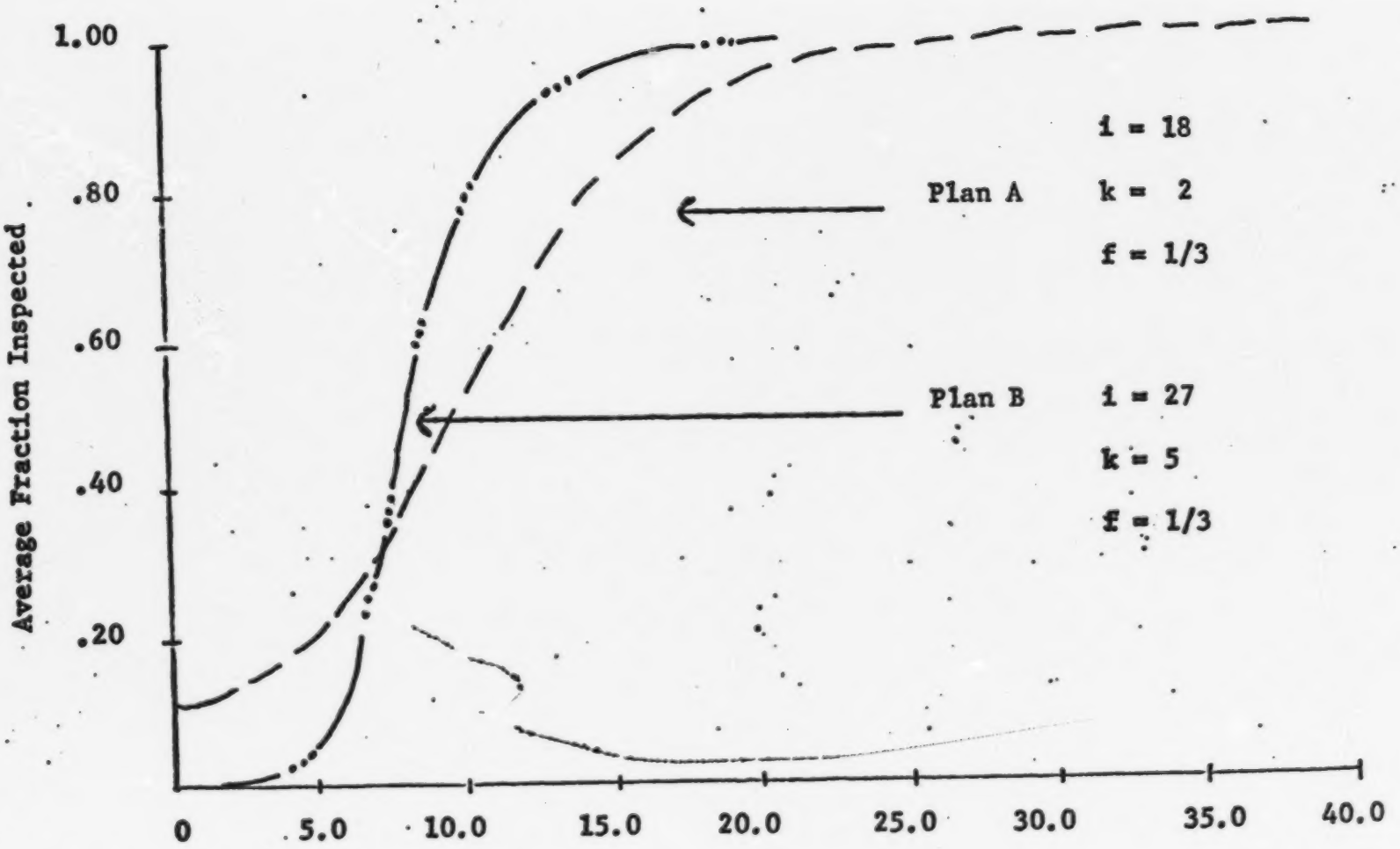
The question immediately arises as to the amount of testing (sample sizes) required under the two plans to insure an AOQL of 5%. Figure IV-3 gives the average fraction inspected (AFI) curves for the two plans. As expected, the fraction inspected under each plan approaches 1.0 (i.e., 100% inspection) as the incoming quality gets poorer (i.e., as p' increases). When p' is less than 7%, plan B will inspect, on the average, fewer units. For values of p' greater than 7% plan A will inspect fewer units because of the smaller value of i for the plan which makes it easier to revert to sampling. A continuous sampling plan may be viewed as a type of sequential test since, in effect, a decision is made after each item inspected. The decision may be to test another unit using the same sampling rate or it may be in the case of a defective unit to revert to a higher sampling rate, perhaps going to 100% inspection.

In summary, the desirable features of continuous sampling which make it amenable to assembly line testing of automobiles are as follows:

a) The plan provides control of outgoing quality. This protection to the public can be set at any desired level and a plan developed to meet that level.

b) Adverse changes in incoming quality are quickly detected and are a signal for initiating corrective action.

Figure IV-3
Average Fraction Inspected Curves



c) Formation of lots is eliminated. Hence, holding or storage areas are not required.

d) The plan provides for a smooth flow of production units through the line.

e) The plan provides an incentive to manufacturers to produce good quality product so as to reduce inspection cost.

V. ASSEMBLY LINE MONITORING

A. Purpose.

The monitoring and auditing of manufacturers assembly line test programs is projected as a Federal function to insure compliance with regulations and standards and to maintain certification of the vehicle types.

B. Difference Between Testing By Manufacturers and Testing for Monitoring.

The examples of sampling inspection plans considered herein for manufacturers are such as are suitable for guaranteeing not more than five percent out-of-specification vehicles in outgoing production. The plans require 100 percent inspection when rejected vehicles are detected. On the other hand, those plans discussed for monitoring purposes guarantee not more than five percent out-of-specification vehicles in accepted lots with prescribed confidence. They are such that a prescribed sample number can be drawn and from them a decision is made that the lot of vehicles is either good or bad. No further obligation for the vehicles exists, insofar as the plan is concerned. Thus the manufacturers plan provides a guarantee that standards are met. The Federal monitoring plan only judges whether the standards have been met.

While these are not the only bases for analysis of sampling inspection plans, they represent a reasonable approach to the problems and responsiblities of each party involved.

C. Certification Control.

The question of what is meant by certification has come up repeatedly in this study, and two answers to this question have been derived. Although they are apparently similar, they are quite different in their effects.

First, one may assume that when NAPCA certifies an engine at some HC value (say, at 1.1 gm/mile), they are stating that they have tested the engine and believe it is capable of this performance. In essence, NAPCA is estimating the emission rate under this assumption.

Under the alternative, it is assumed that certification means only that the engine meets the requirements or limits imposed by NAPCA.

With the first assumption, the concept of "better than" may be imposed. For example, an HC value of 1.1 is "better than" an HC value of 1.5 gm/mile. Under the second assumption, there is no concept of "better than" except between an engine which meets the emission specifications and an engine which doesn't. Under the first assumption, one may wish to determine whether the estimated (certified) emission rates have changed during production without regard, necessarily, for whether the vehicle emission characteristics exceed the maximum requirements. Under the second assumption, interest would center only upon whether the characteristics of production vehicles exceeded the maximum requirements. The recommendations given here are based on both of these assumptions.

The procedure presented below is only one procedure which could be used for such control; it is not suggested that this would be the only or even the best procedure for this purpose.

The vehicles selected for testing should be selected from among those that received the production monitoring tests; in this way the data may also be used to keep the production assembly line test program under control and may also be used to aid in continued establishing standards for assembly line testing. The vehicles would be as carefully tuned and adjusted as they would if they were being presented for certification tests.

At the present time, the regulations require that manufacturers report to NAPCA all changes in the "construction" of an engine after certification, and that NAPCA will decide whether or not each of these changes represents a change in the engine, in relation to certification. The intent of this regulation is to prevent the manufacturers from making modifications to the design or construction of the engine which would increase the emission rates past the allowable limits. However, there are two points of difficulty with this approach:

a) it is often difficult to judge, without subjecting a group of engines to a certification test, whether a specific change would affect the emission rates, and in what direction (let alone by how much!),

b) there are often many changes made in engine design during the year in which the engines are produced, and it is the cumulative effect of all of these changes which is the key factor, not the changes taken individually.

Therefore, it is suggested that a small fraction of the motor vehicles manufactured during the production year be tested, (preferably by NAPCA) using the standard Federal test procedure, and that the degree of conformity of engines to certification requirements be continually assessed from these test results during the year. In general, it is recommended that the sample fraction which the manufacturer is required to test be related to the prior estimates of emission rates on the particular engine family tested, so that if past tests on a family have indicated that the family produces low CO and HC emission rates, then the sample fraction to be tested may be reduced. If, on the other hand, the past results indicate that the emission characteristics of the engine family are close to the allowable limits, then the sample

fraction would be much higher. This policy has two advantages:

a) it rewards those manufactrers who develop and construct low emission engines,

b) given that NAPCA may take some positive and affirmative action (such as revocation of certification) when the test indicates that the engines are out-of-specifications, then such a policy increases the protection to NAPCA against misapplying such affirmative action by reducing the chance of erroneously deciding that a family is out-of-specifications when the family is truly not out-of-specifications.

In carrying out this control function, the manufacturer should be allowed to treat the cars to be tested in the ways now allowed for prototypes, especially with regard to tune-ups and repairs. However, it is not at all certain that the tests would have to be run after 4,000 miles of wear. The evidence on this point is extremely thin; it is suggested that a motor vehicle may possibly receive acceptable wear for such a control test after a much shorter distance. If borne out by data from an experimental program, requiring a shorter distance might allow the manufacturer to still sell these tested vehicles as new. This, of course, would reduce the economic burden on the manufacturer for this type of testing.

It should be pointed out that the hard data on this point seem to be almost nonexistent within NAPCA. Information on emission characteristics below 4,000 miles is sorely needed for the full development of a certification control program and for the development of the second control program, as described below.

D. Assembly Line Production Vehicle Control.

The object of "Certification Control" as described above is to insure

that well adjusted engines continue to meet the minimum certification requirements. However, mass-produced motor vehicles are not generally tuned and adjusted to the same degree as are the certification prototypes, and it is the object of this second control program to monitor motor vehicles--as produced--to insure that they meet certain criteria when they leave the assembly line.

It is suggested that a fraction of motor vehicles be selected at each assembly plant, during each production day, and that these vehicles be subjected to an approved short test. (This may be done by NAPCA or by the manufacturer under NAPCA surveillance.) If the motor vehicle fails to pass certain criteria, then it would be adjusted and retested until it passes. The fraction of failures would be used to determine the fraction of motor vehicles to be tested. Thus the condition could be reached where <u>every</u> vehicle produced would be tested.

The tests for production control and certification control should not be independent; the vehicles selected for certification control testing should be drawn from the fraction of vehicles tested under the production control program. Further, one may wish to adjust the fraction of vehicles tested under the certification control program according to the fraction failing under the production control program. Thus, if the point were reached where all production vehicles were being routinely tested using the short cycle test, and if some large fraction (say, for example, 25%) of these failed the production test, then one may question whether indeed the vehicles are still certifiable or whether, possibly, there has been a change in the correlation between the two tests. For either of these two, the fraction given the longer test should be increased.

E. A Program Scheme for Federal Monitoring of a Testing Program.

Any of several procedures may be employed in determining whether production vehicles continue to meet the certified characteristics of the prototype engine. Lot acceptance, sequential or continuous sampling plans could be considered as possible candidates. The procedure described herein incorporates certain features of each of these plans. The procedure may be applied to the measured parameters carbon monoxide and hydrocarbon either individually or jointly. It may be extended to include NO_x emissions.

Assumptions

Throughout the discussion, it is assumed that production vehicles will be treated and tested in the same manner as was the prototype engine (i.e., NAPCA test @ 4,000 miles). It is also assumed that deterioration factors as obtained from durability tests during certification will be used to determine whether production units meet the specified standards. In this regard, it should be noted that the deterioration factors are estimates of the true factors and, as such, may be in error. This should be taken into account when using these factors for determining units out-of-specification. One method may be to use, for example, the end point of a $(1-\alpha)\%$ confidence interval of the factor rather than the expected value.

Data Needs to Develop the Program.

It is hoped that one would not have to drive vehicles for 4000 miles to predict their performance there. Such a process makes used cars out of new cars and is expensive; what is needed is a determination of the shortest driving distance which correlates satisfactorily with the 4000 mile result. Some of this type of information--for 2000 miles--will be forthcoming shortly from available programs. The question of what constitutes a used car should be considered carefully when deriving the minimum distances.

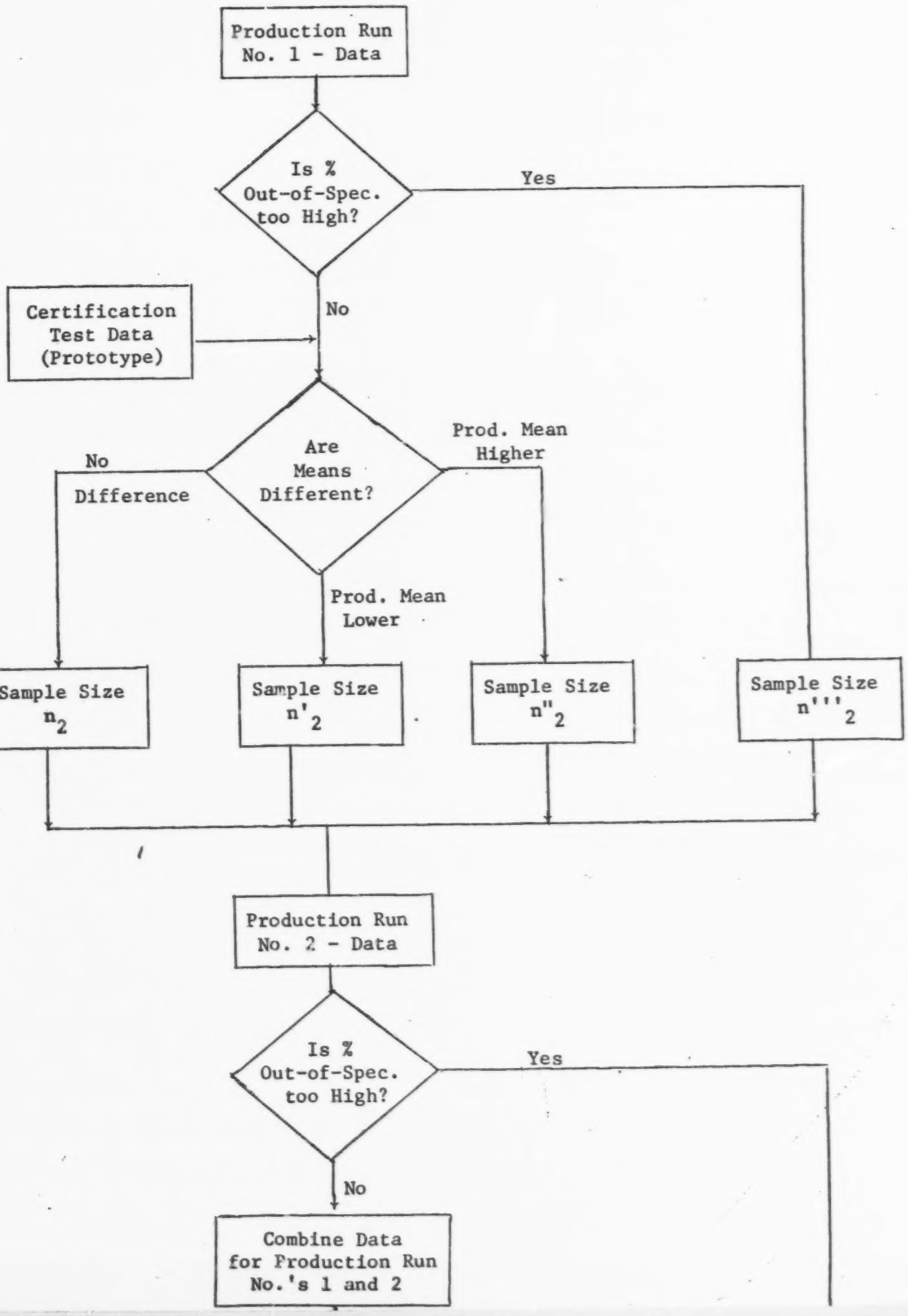
Description of Plan.

A flow diagram of the procedure is given in Figure V-1. The procedure begins with the selection and testing of a sample of n_1 vehicles from Production Run number 1 (to fix ideas, this may consist of one month's production or any other designated group). These sample data are then used to decide whether the percent out-of-specification in the population represented by the sample is too high (the word high needs to be defined numerically, i.e., high could be equal to 5%). If the percentage out-of-specification is judged to be too high, then a sample of size n_2''' is taken from the next production run (number 2). Otherwise, the sample test data are compared with the performance test data of the prototype engine for which the engine was certified. Means, or averages, are compared (t or u-test); if the difference is not significant, then a sample of size n_2 is selected from production run number 2, if the production mean is larger (or smaller) then select a size of n_2'' (or n_2').

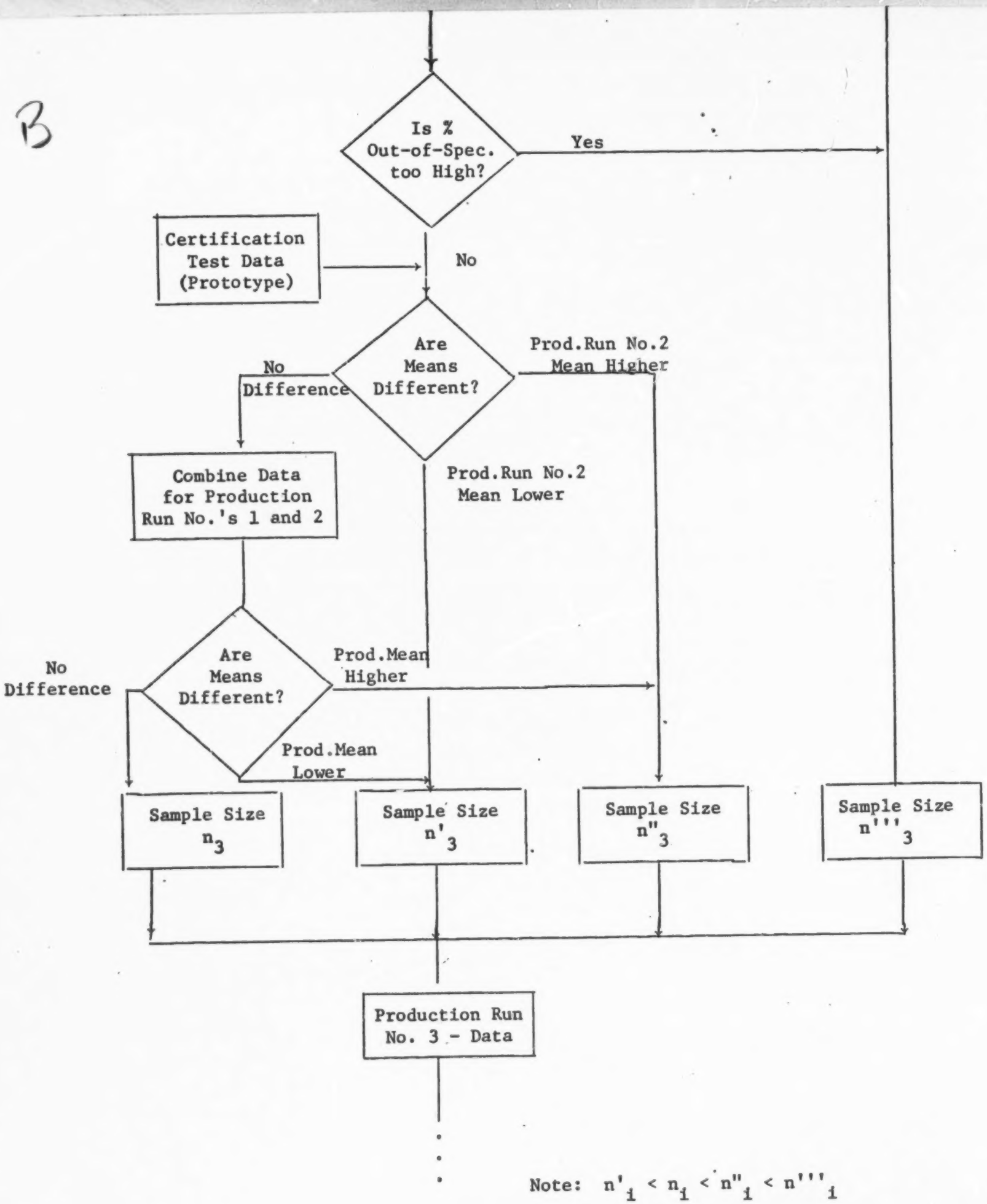
From production run number 2 a sample size of n_2, n_2', n_2'', or n_2''' vehicles are selected and tested. The steps outlined in the preceding paragraph are essentially repeated except that data from production runs 1 and 2 may, under certain conditions, be combined and used as a single sample. The combining of information over both production runs results in the ability to detect smaller differences in the statistical tests because of increased precision in estimating the mean and percentage out-of-specification. The flow diagram in Figure V-1 shows the conditions under which vehicle data are to be combined. In all cases the data should be examined to determine whether it is statistically valid to pool or combine data sets. The final decision of production run number 2 data analyses is based on the sample size for

A

FIGURE V-1


Production Run No. 1 - Data
Is % Out-of-Spec. too High?
Yes
No
Certification Test Data (Prototype)
Are Means Different?
No Difference
Prod. Mean Higher
Prod. Mean Lower
Sample Size n_2
Sample Size n'_2
Sample Size n''_2
Sample Size n'''_2
Production Run No. 2 - Data
Is % Out-of-Spec. too High?
Yes
No
Combine Data for Production Run No.'s 1 and 2

B



Note: $n'_i < n_i < n''_i < n'''_i$

production run number 3 (n_3, n_3', n_3'', or n_3''').

For production run number 3 and subsequent runs, the same general procedure is followed as in production run number 2.

For this procedure, the sample size for the i^{th} production run is determined from the results of the $(i-1)^{th}$ production run alone or from the combined data accumulated over all previous production run samples. For $i \geq 2$, the sample sizes are: n_i, n_i', n_i'', and n_i''' with the restriction $n_i' < n_i < n_i'' < n_i'''$. This restriction allows for reduction in sample size for improvements in performance, increase in sample size for adverse changes in performance (still within specification), and further increase in sample size for adverse changes in percentage out-of-specification. One point should be noted. There are important advantages in increasing the sample sizes during the first weeks of a new production year to allow the suitability of the new production vehicles to be assessed with some high degree of confidence. This may be done easily in such a scheme.

The numerical values assigned to the sample sizes need careful considerations, both from a statistical point of view and practical standpoint. One approach in assigning values to the sample sizes is as follows:

First, determine the total sample size (N) for a given engine class for the entire production period (10 months). This will depend upon the precision desired in the estimate of percentage out-of-specification. Information similar to that given in Figure V-2 will be helpful in making this determination. Figure V-2 shows how the confidence limits decrease with increase in sample size. Also, for any given sample size the width of the confidence interval increases with the level of confidence. Although the values given in Figure V-2 are applicable only for 10% out-of-specification; similar graphs could be

Figure V-2. Confidence Limits on Estimates of Percent Out-of-Specification versus Sample Size (for estimated 10% Out-of-Specification).

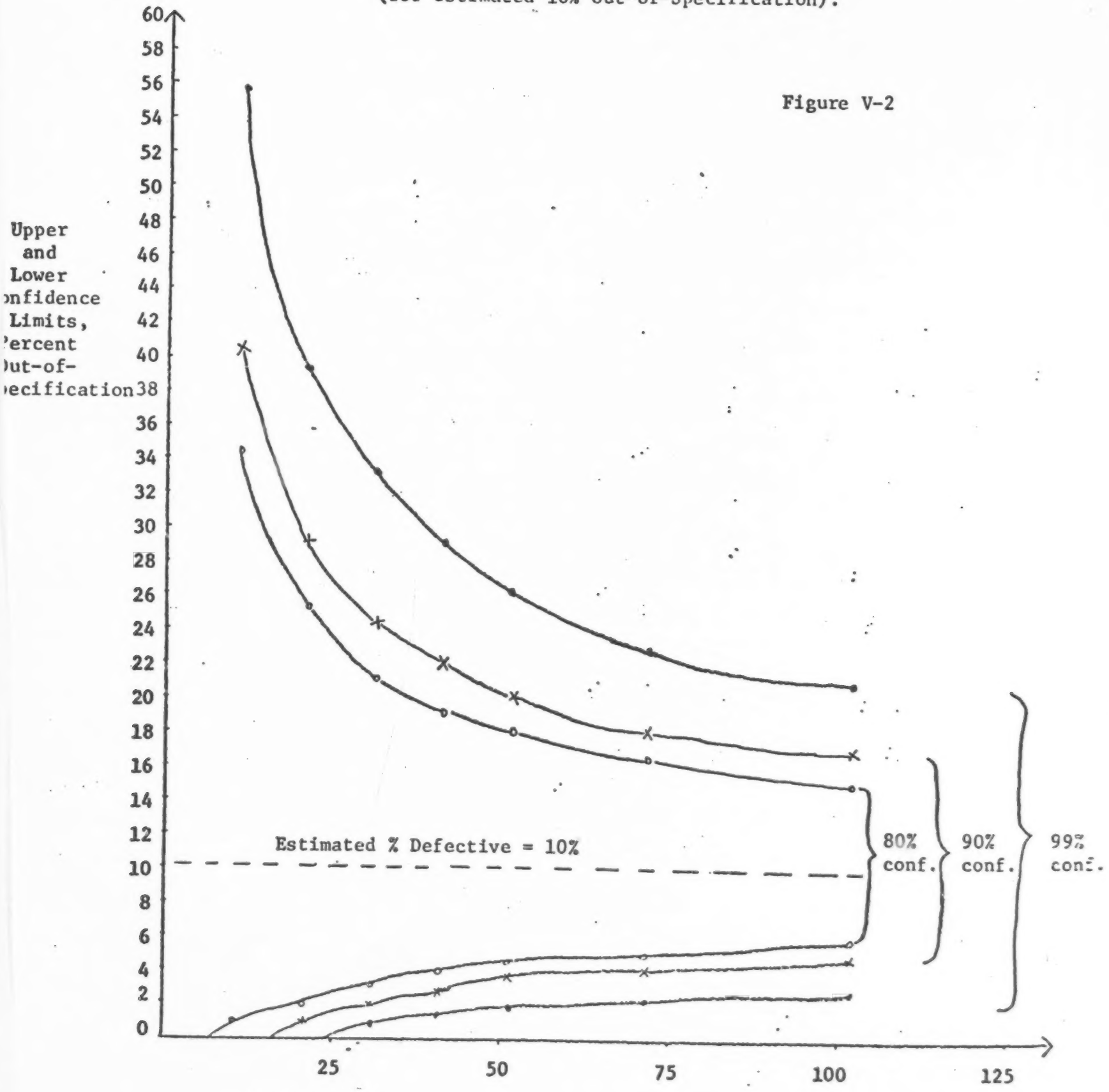


Figure V-2

constructed for other values.

An alternative procedure for determining the total sample size, N, is to establish an overall operating characteristic (OC) curve for the entire production year. This would require levels of "good" and "bad" product quality (expressed in % out-of-specification) to be established; also, the risk of rejecting "good" quality product (a wrong decision known as producers risk, α) needs to be specified, as does the risk of accepting "bad" quality product (a wrong decision known as consumers risk, β). Once the values of α, β, % out-of-specification corresponding to "good," and % out-of-specification to "bad" quality are specified, the sample size, N, can be computed. Having established a total sample size, N, this could be equated to the sum of the individual production run sample sizes n_i. Assuming a production run of one month and a total production period of ten months this becomes

$$N = n_1 + n_2 + \ldots n_{10}.$$

It is desirable to establish as soon as possible whether production units are meeting the certified characteristics. Consequently, the n_i's should decrease with i. A suggested procedure is to take $n_1 = .25N$, $n_2 = .20N$, $n_3 = .15N$, $n_4 = .10N$ and $n_i = .05N$ for $i = 5 \ldots 10$. This would mean that 60% of the total information is available by the end of three months. Determining values of n_i', n_i'' and n_i''' (for $i \geq 2$) would largely depend on the level of quality of the production units. If there is a shift in the average value of the measured characteristic, but the percent out-of-specification is unaffected, then n_i' and n_i'' may be taken as $n_i' = .5n_i$ and $n_i'' = 1.5n_i$. If a significant percentage out-of-specification is noted, then n_i''' may be taken, for example, as $n_i''' = 2.0n_i$. Thus, the

values are subject to alteration but the main idea is to allow the sample size to vary depending upon level of performance of production units.

The procedure just described utilizes attributes data in determining percentage out-of-specification and variables data in determining shifts in mean levels of performance. Variables data could be used to estimate percent defective with greater precision as soon as the underlying distribution of test data has been determined.

VI. COSTS OF TESTING

A. Background.

Tables VI-1 through VI-5 summarize the estimated investment, facility, and test personnel costs to the major American manufacturers for setting up and carrying out assembly line testing. Costs to foreign manufacturers based upon their acting cooperatively in the conduct of tests at major customs unloading districts are also shown. In tabulating the cost estimates, both 100 percent inspection and sampling inspection have been considered for American manufacturers, while only 100 percent inspection was considered for foreign manufacturers.

Where sampling inspection is considered the average quality level to be held for outgoing automobiles was set for comparison at 5 percent and 10 percent "out-of-specification." Average quality submitted was considered at both 5 or 10 percent. Only continuous sampling was considered for American manufacturers. The average number of tests per month was estimated from the assumed incoming quality and outgoing limit, using the formula:

(Monthly production rate)(average fraction inspected) =

Average number inspected.

The Average Fraction Inspected (AFI) is obtained from Figure IV-3, (Plan B) for Tables VI-3 and VI-4. The AFI for Tables VI-5 and VI-6 is given in the Department of Defense Handbook H-106: "Multi-Level Continuous Sampling Procedures and Tables for Inspection by Attributes."

Equipment needs to match the number of tests required were defined by assuming that a short test requires 4 minutes. Most short tests (KEY MODE,

TABLE VI-1

Average Number of Tests Per Month Required
Under Continuous Assembly-Line Sampling Plan B

Conditions	Average Number of Automobiles Tested Per Plant Per Month				
	American Motors	Chrysler	Ford	General Motors	Foreign Manufacturers*
Production rate	15,700	23,500	22,800	22,861	---
AOQL 5%					
IQL 5%	942	1,410	1,370	1,252	---
IQL 10%	12,100	17,000	17,600	16,000	---
AOQL 10%					
IQL 5%	157	235	228	209	---
IQL 10%	1,100	1,645	1,500	1,460	---

Notes: AOQL = Average Outgoing Quality Limit, % out-of-specification
IQL = Incoming Quality Level, % out-of-specification

* Sampling Inspection NOT CONSIDERED FOR FOREIGN MANUFACTURERS.
See TABLE VI

TABLE VI-2

Sampling Inspection Costs, $/Vehicle

Manufacturer	Annual Production	Annual Cost $/Vehicle Produced							
		5% AOQL				10% AOQL			
		5% IQL		10% IQL		5% IQL		10% IQL	
		f*	cost	f	cost	f	cost	f	cost
Am. Motors	309,000	(0.06)	1.40	(0.77)	2.80	(0.01)	1.40	(0.07)	1.40
Chrysler	1,850,500	(0.06)	0.94	(0.77)	1.89	(0.01)	0.94	(0.07)	0.94
Ford	2,777,900	(0.06)	1.40	(0.77)	2.80	(0.01)	1.40	(0.07)	1.40
Gen. Motors	5,215,300	(0.06)	1.03	(0.77)	2.09	(0.01)	1.03	(0.07)	1.03
Total	10,152,700								
Average			1.19		2.40		1.19		1.19

	Total Cost, First Year $/Vehicle Produced			
	5% AOQL		10% AOQL	
	5% IQL	10% IQL	5% IQL	10% IQL
American Motors	1.73	3.80	1.73	1.73
Chrysler	1.16	2.54	1.16	1.16
Ford	1.73	3.80	1.73	1.73
General Motors	1.29	2.79	1.29	1.29
Average	1.48	3.23	1.48	1.48

* f = fraction inspected

TABLE VI-3

Comparison of Sampling Inspection Costs
Continuous Sampling Plan
Basis: 10,153,000 Automobiles

Conditions	Type of test	First Year Cost		Annual Cost	
		Total Cost	Per/Car Produced	Total Cost	Per/Car Produced
AOQL 5%					
IQL 5%	Short	$ 15,026,000	1.48	$ 12,082,000	1.19
	NAPCA	36,494,000	3.59	26,770,000	2.64
IQL 10%	Short	32,794,000	3.23	24,367,000	2.40
	NAPCA	404,802,000	39.87	316,671,000	31.19
AOQL 10%					
IQL 5%	Short	15,026,000	1.48	12,082,000	1.19
IQL 10%	Short	15,026,000	1.48	12,082,000	1.19

TABLE VI-4

Sampling Inspection Costs for Plan Utilizing
Both Short and NAPCA-1370 Second Test
Assuming AOQL = 5% and IQL = 10%
Basis: 10,153,000 Automobiles

Test	First Year Cost $		Annual Cost	
	Total	Per Car	Total	Per Car
Short	32,793,000	---	24,366,500	---
Repeat	6,968,000	---	5,610,000	---
NAPCA	38,300,000	---	29,006,500	---
Total	78,061,000	7.69	59,006,500	5.81

TABLE VI-5

Cost of 100% Inspection

Producers	Total Production per plant per mo.	No. of Testing Units per plant	Cost/Plant ($1000) Equipment & Facilities	Cost/Plant ($1000) Staff	No. of Plants	Total Cost ($1000) First Year	Total Cost ($1000) Annual
Am. Motors	$15,700	2	$ 116	$ 420	2	$ 1,072	$ 863
Chrysler	23,500	3	174	630	8	6,432	5,179
Ford	22,800	3	174	630	18	14,472	11,653
General Motors	20,861	3	174	630	25	20,100	16,185
Foreign Manufacturers	10,000	2	116	280	14	5,544	4,082
Total						$47,620	$37,962

	Total Unloaded per mo.	No. of Testing Units per Unloading District	No. of Unloading Districts

	$/Vehicle First Year	$/Vehicle Annual
American Motors	$3.47	$2.75
Chrysler	3.42	2.75
Ford	3.53	2.84
General Motors	3.85	3.10
Foreign Manufacturers	3.27	2.41

EXIT, ACID) require one minute running time, or 1 1/4 minutes if NO_x is to be monitored. The extra time was allowed for turnaround.

The NAPCA (7 mode or 1370-sec) test was assumed to take one hour.

Short test equipment costs were estimated at three levels. For a U.S. assembly plant, where equipment is to meet the requirements of the U.S. Industrial Conference Code, the estimated cost breakdown is:

dynamometer	$11,000
instrumentation	17,000
computer	10,000
total equipment	$38,000

For high volume duty, as required by most import vehicle manufacturers, the breakdown is:

dynamometer	$ 6,000
instrumentation	17,000
computer	10,000
total	$33,000

For modest volume duty as required by low-volume importers:

dynamometer	$ 4,200
instrumentation	7,000
computer	none
total	$11,200

The site cost in all three cases was taken at $20,000.*

The 1972 Federal test procedure requires equipment estimated at $62,000:

*These estimates are based upon discussions with Mr. E. L. Cline, Clayton Manufacturing Company, El Monte, California.

C.V.S. (Constant Volume Sampling) system	$10,000
Gas analysis system	25,000
Dynamometer	5,000
Data analysis system	2,000
Miscellaneous hardware	10,000
Support expense, including maintenance of calibration gases	10,000
	$62,000

The site cost was taken at $20,000, as for the short test.

A computer at each test station was considered necessary, except for the low-volume import manufacturer.

American Manufacturers.

The cost estimates were made using 1970 sales estimates, cataloged according to major manufacturer. [8] A breakdown of these estimates according to assembly plant is not available. For this reason, the production in (vehicles/month) was assumed to be one-tenth of the annual sales forecast (a ten-month period) spread evenly over each plant.

Two technicians and one inspector were assumed necessary for each test unit, although in practice, one supervisor may handle two test units. Technicians were costed at $20,000/year; supervisors, at $30,000.

The first year cost includes equipment plus personnel. The annual cost is the annual personnel cost plus 0.1 the equipment and facilities cost.

Foreign Manufacturers.

Imported vehicles are assumed to be inspected at the customs district of unloading. A complete record of unloadings at customs districts for 1969 is given in Table VI-6. This table shows the totals for each district received from each of the nine major countries of origin. Using this table as a basis, the fourteen unloading districts receiving the largest numbers of

TABLE VI -6

Numbers of Foreign Automobiles Imported During 1969
By Country of Origin and District of Unloading

District of Unloading	Country of Origin									Total for District of Unloading
	W. Germany	Japan	Britain	France	Belgium	Italy	Canada	Canada, T. A.	Sweden	
Portland, Me.			64				290	3	30	387
St. Albans, Vt.								1		1
Boston	23,047	6,402	1,574	691		4				31,718
Providence, RI.	1,490									1,490
Bridgeport, Conn.				82					5,503	5,585
Ogdenberg, N.Y.			1	152			240	57,078		57,471
Buffalo, N.Y.			12				123	362,223		362,358
New York City	101,787	25,548	21,309	6,466	5,779	9,785			16,662	187,336
Philadelphia			2	80	31	28				141
Baltimore	134,478	16,918	26,299	3,851	8,991	10,692			2,762	203,991
Norfolk, Va.	65	3,429	228	2,469	6					6,197
Charleston, S.C.		21	884							905
Savannah, Ga.	3,254		27	27	8,781					12,089
Tampa, Fla.	42,476	20,867	6,649	587		3,092			2,534	76,205
Mobile, Ala.			858	363		68			1,205	2,494
New Orleans	36,329	23,395	3,303	758	981	1,719			1	66,486
Port Arthur, Tex.	19,868		1							19,869
Galveston, Tex.		135	1,811		8,328	11				10,285
Los Angeles	79,724	75,316	2	2,618		7,341			4,485	169,486
San Francisco	51,384	25,774	10,584	1,412	1,845	3,770			3,263	98,032
Portland, O.	15,993	11,833	2,385	364	2,757	707			1,123	35,162
Seattle	9,061	7,853	880	609		906	1	2	1,109	20,421
Honolulu	4,468	8,898	457						34	13,857
Anchorage, Al.	2									2
Great Falls, Mont.								1		1
Duluth, Minn.	2		2				1			5
Detroit, Mich.	23	1	1,615	283	460	307	201	264,663	1	267,554
Chicago	29,385	23	12	3						29,423
Cleveland, O.	42,355	7	1							42,363
San Juan, P.R.	7,377	13,956	3,124	811		311		6,323	317	32,219
Miami, Fla.	1,233	83	1,248	1,258		162			8	3,952
Houston, Tex.	38,355	16,156	3,362	1,573	3,819	2,666			1,971	67,902
Washington, D.C.	1	1								2
Totals:	642,157	256,575	86,695	24,457	41,778	41,569	856	690,294	41,008	1,825,389

Source: Department of Commerce, Bureau of Census, Trade Information Branch.

vehicles were selected. For these, the average number per month was estimated at 10,075. (Table VI-7). This number was used to estimate the costs to foreign manufacturers, acting cooperatively to establish, operate, and maintain a testing station at each of 14 major unloading districts. The different types of costs estimated total are first year costs, annual costs, and costs per vehicle, the same as for American-manufactured vehicles.

B. Costs of Sampling Inspection.

Since sampling inspection costs vary with the percent "out-of-specification" in the vehicles submitted for inspection, estimates have been developed to show this effect. In all cases, the limit of five percent has been placed on outgoing "out-of-specifications" vehicles. The average outgoing quality limit (AOQL) has been set at 5% and 10%. The incoming quality level (IQL) that is, the percent "out-of-specification" actual present in vehicles submitted for inspection, has been set at 5% and 10% also. The choice of these levels permits evaluation of three different circumstances: 1) where the incoming quality equals the outgoing limit, 2) where the incoming quality is better than the outgoing limit (5% IQL, 10% AOQL), and 3) where the incoming quality is worse than the outgoing limit (10% IQL, 5% AOQL). Table VI-1 shows the number of tests per month required under each of these circumstances. For example, American Motors will expect to test 942 vehicles per month per plant if their IQL is 5% out-of-specification. They will expect to test 12,100 per month per plant if their IQL is 10% out-of-specification.

Sampling Inspection Cost Calculations.

The costs shown in Table VI-2 were developed as shown by the following example:

American Motors estimates the manufacture of 309,000 automobiles during

TABLE VI-7

Automobiles Received at Each of the Major Unloading Districts During 1969

District of Unloading	Total Vehicles Received
Buffalo	362,358
Detroit	267,554
Baltimore	203,991
New York City	187,336
Los Angles	169,486
San Francisco	98,032
Tampa	76,205
Houston	67,902
New Orleans	66,486
Ogdenburg, N. Y.	57,471
Cleveland	42,363
San Juan, Puerto Rico	32,219
Boston	31,718
Chicago	29,423
Total	1,692,544
Average number per year per district	120,896
Average number per month per district	10,075

1970. This is equivalent to 15,700 per plant per month. Assume only five percent of these, as submitted for inspection, would fail to meet standards. For sampling plan B, figure IV-3 shows the average fraction inspected to be 0.06. The number inspected would therefore be:

$$15{,}700 \times 0.06 = 942$$

production/month/plant x fraction inspected = number inspected per plant per month

One test unit plus facilities will test 9000 cars/month. For American Motors, one unit plus facility is required per plant. Accordingly, the equipment plus facility cost per plant is:

$$\$38{,}000 \times 1 + \$20{,}000 = \$58{,}000$$

test unit cost + facility cost = cost per plant

If two 10-hour shifts per day are to be scheduled, 30 days per month, the hours worked amount to 140 per week. This requires between three and four crews, consisting of a supervisor at $30,000 year total cost plus two technicians at $20,000 per year total cost for each. Assume three crews are used. Staff costs are then:

$$3 \times \$70{,}000 = \$210{,}000$$

crews required x annual cost/crew = total annual staff cost.

From these costs, the total first-year cost is obtained:

$$2\ (\$58{,}000 + \$210{,}000) = \$536{,}000$$

(number of plants)(equipment and facilities + staff) = total first year cost.

The total annual cost is the annual labor cost plus one tenth the equipment and facilities cost:

$$2\ (\$210{,}000 + 5{,}800) = \$431{,}600$$

plants (staff cost + 0.1 equipment cost) = total annualized cost.

The cost per automobile produced would be:

first year cost: $536,000/309,000 = $1.73

Annualized cost: $431,600/309,000 = $1.40

C. Costs of Applying the Hot-Start, 1370-second Federal Test.

If hot-start NAPCA-1370-sec. tests were run instead of the above-mentioned short tests, the annual cost per car would be higher, by an amount which depends again upon the incoming quality level. This is evident by comparing the cost per car for the short test with the NAPCA test given in Table VI-3. For an incoming quality level of 5%, the annual cost per car produced goes from $1.19 to $2.64. On the other hand, if the incoming quality level is 10%, the cost increases from $2.40 when the short test is employed to $31.19 when using the NAPCA test. Further comparisons of total inspection costs and annual inspection costs are shown in Table VI-3.

D. Costs of Using Short Test Along with Federal Test as a Standard.

Table VI-4 provides an assessment of the effect of using the NAPCA-1370 second test as the ultimate standard against which any car must be compared before it can be considered rejected, and before the certification can be revoked. This type of test procedure was suggested in [8] and is considered in this report only for cost comparison. The sequence of testing under this concept is

1) apply short test;

2) if 1) is failed, reapply short test;

3) if 2) is failed, apply 1370-test;

4) if 3) is failed, reapply 1370-test.

This procedure ends at step 1) for acceptable cars.

For costing purposes, an AOQL of 5% and an IQL of 10% were assumed. The amount of retesting expected under this procedure was taken into account

1970. This is equivalent to 15,700 per plant per month. Assume only five percent of these, as submitted for inspection, would fail to meet standards. For sampling plan B, figure IV-3 shows the average fraction inspected to be 0.06. The number inspected would therefore be:

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production/month/plant x fraction inspected = number inspected per plant per month

One test unit plus facilities will test 9000 cars/month. For American Motors, one unit plus facility is required per plant. Accordingly, the equipment plus facility cost per plant is:

$38,000 x 1 + $20,000 = $58,000

test unit cost facility cost cost per plant

If two 10-hour shifts per day are to be scheduled, 30 days per month, the hours worked amount to 140 per week. This requires between three and four crews, consisting of a supervisor at $30,000 year total cost plus two technicians at $20,000 per year total cost for each. Assume three crews are used. Staff costs are then:

3 x $70,000 = $210,000

crews required x annual cost/crew = total annual staff cost.

From these costs, the total first-year cost is obtained:

2 ($58,000 + $210,000) = $536,000

(number of plants)(equipment and facilities + staff) = total first year cost.

The total annual cost is the annual labor cost plus one tenth the equipment and facilities cost:

2 ($210,000 + 5,800) = $431,600

plants (staff cost + 0.1 equipment cost) = total annualized cost.

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3) if 2) is failed, apply 1370-test;

4) if 3) is failed, reapply 1370-test.

This procedure ends at step 1) for acceptable cars.

For costing purposes, an AOQL of 5% and an IQL of 10% were assumed. The amount of retesting expected under this procedure was taken into account

in calculating the cost estimates shown in Table VI-5. Cost per car under this test plan further supports the need for a short test with sufficient correlation with the NAPCA test.

E. Costs of 100 Percent Inspection.

Table VI-5 shows the costs of 100 percent inspection. (The labor costs are developed as shown in the example calculation for sampling inspection.)

The first year cost totals $47,620,000 for all four major U.S. producers and foreign cars tested at district of unloading. The corresponding annual cost totals $37,962,000. On a per car basis, it would cost the U.S. industry $2.75 to $3.10 for 100 percent assembly line testing, using a short test. Foreign manufacturers would incur an annual cost of $2.41 per car.

F. Light and Heavy-Duty Vehicles.

Costs of assembly-line testing for light and heavy-duty vehicles (trucks, with gasoline or diesel engines) have not been developed, because of insufficient data. It is suggested, however, that the sampling-inspection plans could apply to these vehicles also.

VII. COSTS OF MONITORING ASSEMBLY LINE TESTING

In monitoring the testing procedures, the following activities should be covered: calibration control, control of quality of data collection and transmission, and overall procedures control. A program such as the one described here will require a field staff for effective monitoring of activities. One should not be surprised to find that the program requires at least one NAPCA representative at each major assembly plant, full time for the first year or so. After procedures are implemented and working properly, the number of field representatives may be reduced somewhat. To start, however, it is estimated that monitoring will require a staff of 67 at an annual cost of $2,341,600, based on $15,000 basic salary, plus 133% effective overhead. The total cost, including equipment and support, is estimated at $4,418,600. The estimates were made as follows.

1)	53 number of major assembly plants	x	$34,950 salary and overhead	=	$1,852,350 annual staff cost, American vehicles
2)	14 number of major districts of unloading	x	$34,950 salary and overhead	=	$489,300 annual staff cost, foreign vehicles

Note: This is based upon conducting tests at only the 14 customs districts where the major proportion of vehicles are unloaded.

3) Total staff costs:

$1,852,350 + $489,300 = $2,341,650.

4) Miscellaneous equipment, to check calibration of instruments, etc.

67	x	$10,000	=	$67,000
number of staff		equipment per staff member		

5) Supplies, maintenance, and communication, including support from DMVPC headquarters.

67	x	$30,000	=	$2,010,000
number of staff		cost per staff member		

6) Total Monitoring Costs

Staff	$2,341,650
Equipment	67,000
Support	2,010,000
Total	$4,418,650

NAPCA should assume another vital role in monitoring the assembly line testing--namely, making sure that accrued costs of testing are not inflated when they are passed on to the purchaser of the automobile. The cost estimates in this report indicate that a very modest increase in cost to the purchaser--not to exceed $5.00--would be sufficient to take care of the testing operation alone. In connection with NAPCA's overall objectives, it is important for it to see that these costs are not utilized as an excuse for increases in automobile costs of 5% or more. Since cost estimates contained herein are only estimates based on the best information available, one objective of monitoring should be to provide better cost figures and to maintain and abate the actual costs found to accrue under the assembly line testing program.

VIII. IMPLEMENTATION

The steps required to develop the plan for the control of light motor vehicles are given below. The steps are numbered serially, and numbers given to the right of each step define the prerequisite steps for initiation of that step. Lead times are estimated, based upon the Institute's experience in developing full-scale quality-assurance programs for large industrial processes. Lead time means the time estimated to be required from start of the step until the step is completed.

1. Obtain agreement on an overall plan outline and ascertain whether legal questions as to the limits of power need to be answered. (Lead time: 2 months. However, legal questions must be continually answered through out the development program.)

2. Develop, cooperatively with automotive manufacturers, dynamometer manufacturers, and interested parties in various states and AQCR's, a short emission test with diagnostic potential which correlates adequately with the federal test procedure.

   Determine characteristics of the test, and develop specification on equipment calibration, operation, and control of quality of measurement. (Lead time: 12 months.)

3. Begin collection of primary and secondary data on the question of the changes in engine performance from green engines to 4000 miles. Determine relative degrees of predictability at various mileages, and select a mileage for use in certification maintenance testing. (Lead time: 12 months. This step will continue through the first three years, however.)

4. Field test the method in several locations (hopefully, in two or three states and in two or three manufacturer's locations). (Lead time: 10 months.) (2)

5. Develop detailed sampling plans for use in assembly line testing and for use in assessing imported lots of vehicles. (Lead time: 9 months.)

6. Integrate critical limits and sample sizes so as to achieve desired sampling plan. (Lead time: 7 months.) (2,3 4,5)

7. Develop detailed information on the work loads in each assembly plant (with forecasts) and in each port of importation, and calculate the costs for several strategies (e.g., it might be possible for Fiat to combine testing stations with others such as Lotus; obvious matches should be explored from an economics point of view). (Lead time: 8 months.) (5)

8. Develop the detailed plans for the control of (maintenance of) certification, including sampling plans, and develop economic cost ranges. (Lead time: 6 months.) (3,5,6)

9. Make disclosures of plans to industry, and request that industry both comment on the plans and develop a tentative phased schedule for inauguration by a NAPCA-determined date. (Lead time: 8 months.) (7)

10. Develop plans for the evaluation of the effectiveness of the control system, including data requirements. Develop procedures for use of evaluation results in the monitoring of the programs. (Lead time: 3 months.) (7,9)

11. Develop an information storage and retrieval system for the program; request cooperation from manufacturers to supply data in machine readable form. (Lead time: 6 months.) (8,10)

12. Conduct limited field test of the system in at least two plants (see Item 4, above), and collect sufficient data to demonstrate total feasibility, including NAPCA servicing (such as calibration checking). Hire and train part of field staff. (Lead time: 5 months.) (10)

13. Develop detailed plans for monitoring of the control process. (Lead time: 4 months.) (11,12)

14. Develop an organizational structure for the administration of the control program, including levels of staffing required. (Lead time: 8 months.) (13)

15. Write detailed manuals (documentation) on the methods and procedures to be followed. (Lead time: 3 months.) (13)

16. Initiate. (14,15)

An implementation chart, showing the 16 steps and the critical sequences involved, is shown in Figure VIII-1. The critical sequences are: Develop short test → field test method → finalize standards for sampling plans → detailed plan for control of certification; disclosure to industry and receipt of their plans → plans for testing system evaluation → information retrieval system; and detailed plan for monitoring → development of organization. A total time to implementation of 64 months is estimated. Steps 1, 2, 3, and 5 can begin at once. The development of a short test (step 2) should be supported by statistically designed experiments in order that data will be developed for step 6, the finalizing of standards for sampling plans. In development of this test, proper correlation with the certification test is a major item. Basic statistical tables will be required. (See Section III-D)

The sequencing chart, Figure VIII-1, displays the critical path by a dotted heavy line, and displays the times required for each task (in months) by numbers on each sequencing arrow. This information is also displayed on a Gantt chart

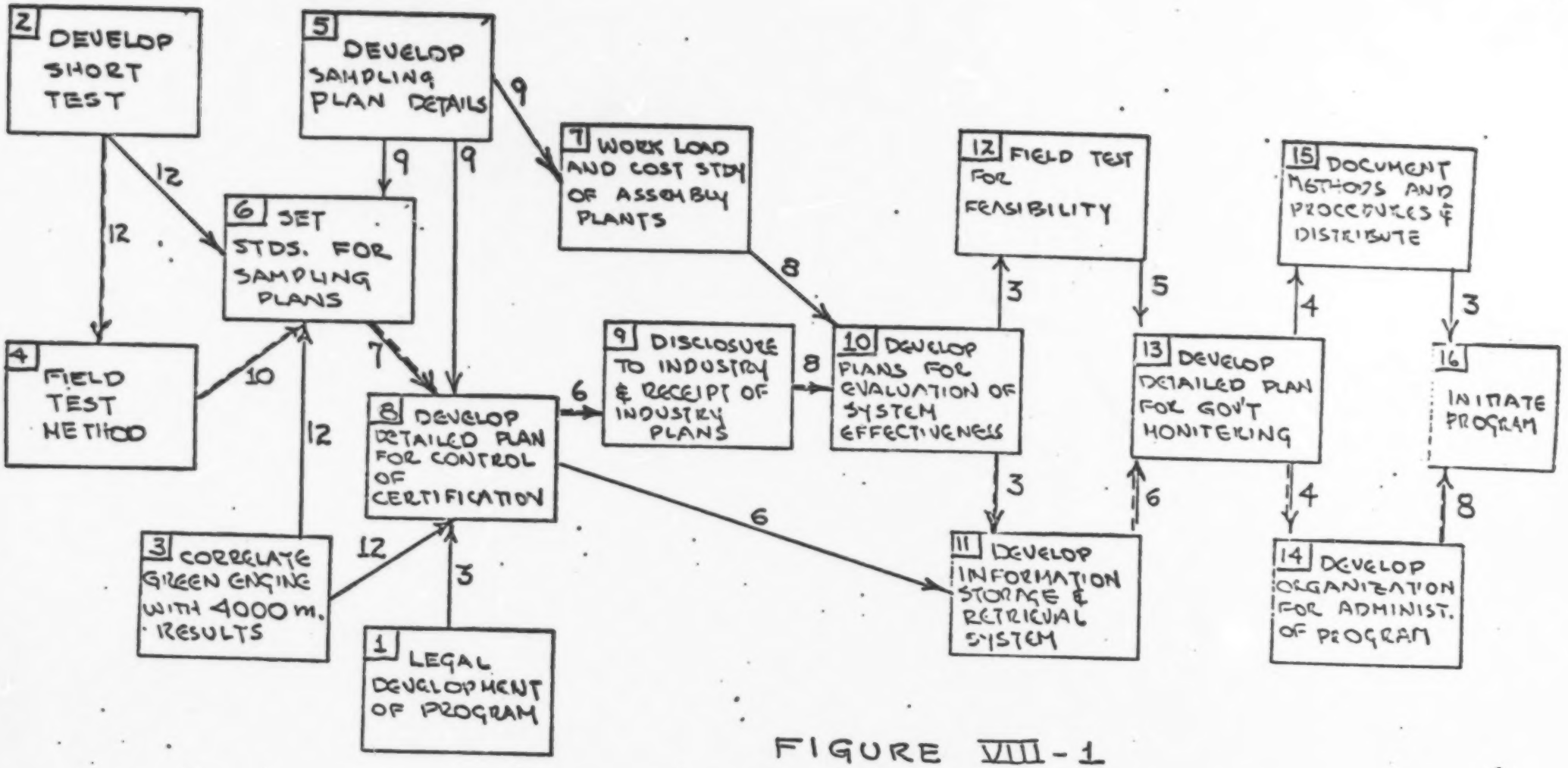


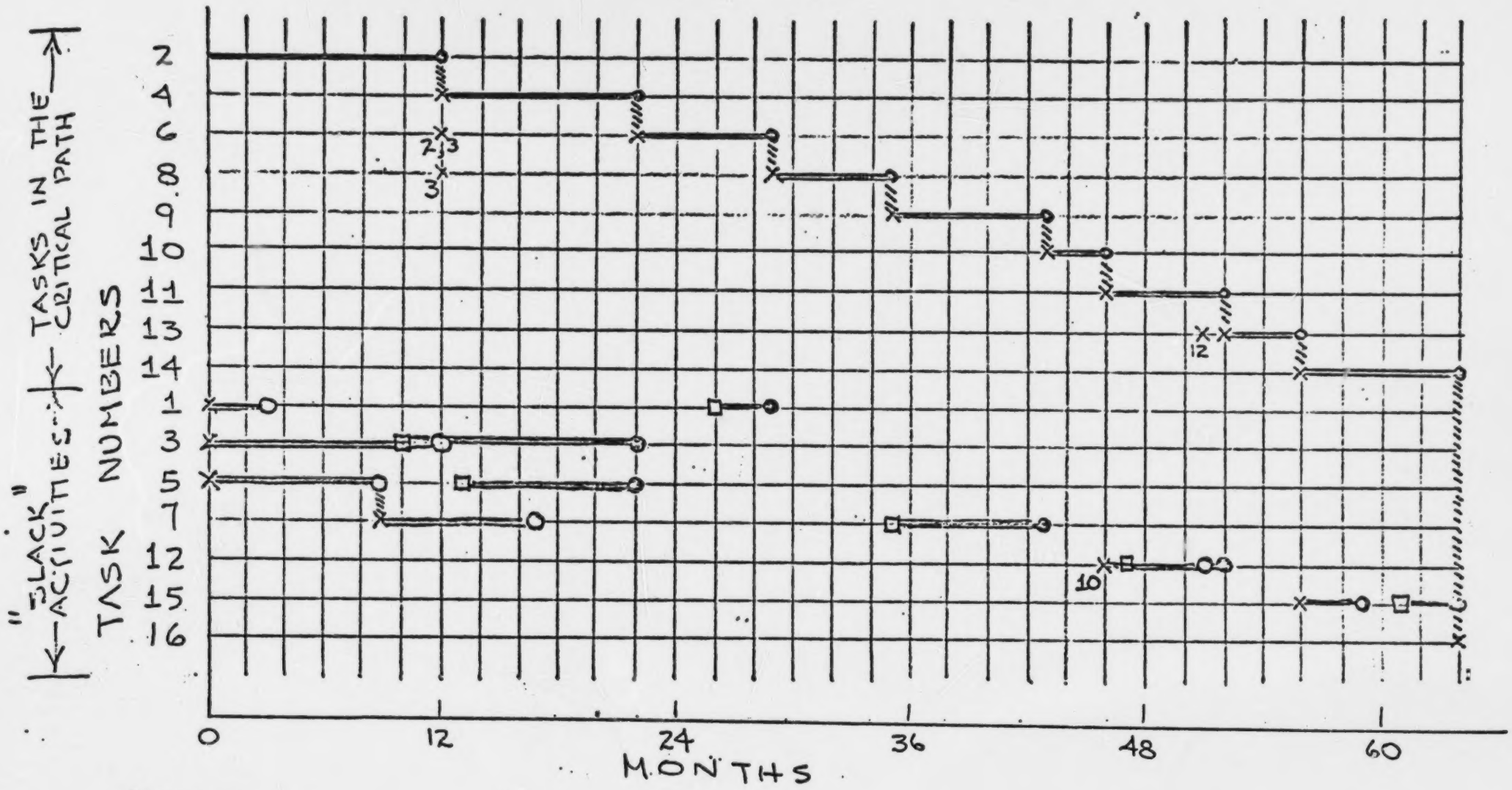
FIGURE VIII-1

ASSEMBLY LINE TESTING IMPLEMENTATION CHART

(SHOWING CRITICAL PATHS AS DOTTED LINES AND TIMES REQ'D IN MONTHS FOR EACH PATH.)

in Figure VIII-2; the first nine tasks shown on this chart are those in the critical path; the last six are activities for which some slack time is available for scheduling, as shown on the chart.

FIGURE VIII-2
ASSEMBLY LINE TESTING SCHEDULING CHART
(SHOWING SLACK ACTIVITIES AND TIMES)



NOTATION:

- X EARLIEST TIME TASK MAY BE STARTED
- ● LATEST TIME TASK MUST BE COMPLETED
- □ LATEST TIME TASK MAY BE STARTED } FOR SLACK ACTIVITIES ONLY.
- ○ EARLIEST TIME TASK MAY BE COMPLETED }

IX. ANALYSIS OF CARB ASSEMBLY LINE DATA ON FORD AND CHRYSLER VEHICLES.

Background

The atuomotive industry has been submitting data to the State of California since the first of this year (1970) on the emission characteristics of motor vehicles, measured at the end of the assembly lines, which are destined for sale in California. The information from Ford and Chrysler for the first quarter of 1970 is summarized below in Tables B-1 and B-2. Information from GM was not received, in machine readable form, in time to be analyzed for presentation in this report.

Analysis of the Data

After summarizing the data according to the means and standard deviations for each make, engine size, and other characteristics, an attempt was made to extract as much information as possible from the data. The results of these analyses are presented in the next several paragraphs.

FORD DATA:

The data presented by Ford were first summarized in a table according to the make of the vehicle and engine displacement. When this was done, it was seen that only a few direct comparisons could be drawn among these data. These were made, where possible, (using Student's t-test or other appropriate tests) with the results presented below:

(a) Manual vs. Automatic Transmissions

	HC	CO
Maverick, 170 CID, IV	sig, >	sig, >
Maverick, 200 CID, IV	sig, >	sig, <
F-100, 300 CID, IV	not sig.	not sig.
F-100, 360 CID, 2V	sig, >	sig, <

In general, these vehicles with these two types of transmissions produce significantly different levels of emissions. The "automatics" produced higher levels of HC than did the manual transmission vehicles, but the picture for CO is confused, with the "automatics" higher in one case, but lower in two cases. Note that the one case of "nonsignificance" occurred in the case with the smallest size of sample.

(b) Vehicles

These data allow a limited test of whether emission characteristics change for a given engine, carburation, and transmission when this drive train is placed in a different model. Results are given below:

	HC	CO
250 CID, 1V, Auto: Maverick vs Fairlane	not sig.	not sig.
351 CID, 4V, Auto: Mustang vs Ford	sig.	not sig.
302 CID, 2V, Auto: (Montego, Fairlane, Mustang, Falcon)	not sig.	not sig.

Except for the one case, no significant differences were found.

(c) Engine Size

It comes as no surprise to find that different emission characteristics arose from engines of different displacements, as summarized below:

	HC	CO
Maverick, Manual, 170 vs 200	sig. >	sig. <
Maverick, Auto, 170 vs 200	sig. >	not sig.
Ford, Auto, 2V, 390 vs 429	not sig.	sig. >
Ford, Auto, 2V, 351 vs 429	sig. >	sig. >
Ford, Auto, 2V, 351 vs 390	sig. >	sig. >

For those cases showing significance, the smaller engines always produced more hydrocarbons and in three of four cases produced more CO.

CHRYSLER DATA:

Similar analyses were conducted on data from Chrysler, as presented below:

(a) Effect of Air Conditioning

Three direct comparisons were possible between vehicles with and without air conditioning. These cases were for Challenger 318 CID automatic, Valiant 225 CID automatic, and Dart 225 CID automatic vehicles. There were no significant differences in either HC or CO due to the addition of air conditioning.

(b) Vehicles

For the 318 CID engine with automatic transmission, comparisons were made between Dart, Fury, Belvedere, Coronet, and Challenger. In general, there were no significant overall differences in either HC or CO, even though one or two pair-wise comparisons might show such significance.

Comparisons with Certified Values

The results are compared below with values as certified by NAPCA; in general such comparisons must be made with some care. For example, the NAPCA certified values have been sales weighted, but in several cases, results from all of the different combinations which could be made did not appear in the data from the manufacturers and thus it was not possible to sales weight the assembly line results as was done during original certification. The results of this comparison are given below:

Ford:

CID	HC Assy.	HC Cert.	CO Assy.	CO Cert.
170	1.89	1.95	10.90	12.29
200	1.81	1.88	14.10	13.90*
240	2.02	1.80*	16.76	8.47*
250	1.78	1.77	16.20	11.74*
300	1.61	1.85	16.51	14.65*
302	1.94	1.86*	19.07	15.43*
351	2.13	1.94*	20.13	15.78*
360	1.60	1.77	18.33	16.42*
390	2.02	1.66*	17.56	12.80*
429	1.90	1.96	16.23	18.04
460	2.17	1.88*	15.45	16.82

Chrysler:

2 hot cycles for assembly line testing

CID	N	HC Assy.	HC Cert.	CO Assy.	CO Cert.
198	5	2.30	1.50*	28.12	7.99*
225	85	1.75	1.37*	14.50	10.88*
318	159	1.30	1.75	8.75	10.74
340	9	2.04	1.78*	22.10	8.88*
383-2V	52	1.70	1.71	13.36	13.17*
383-4V	36	1.54		20.55	
440	21	2.04	1.65*	16.78	8.26*
440 HP	5	2.04		14.42	
440-6	1	2.39		26.40	

The last two cases (383 and 440 CID) have not been averaged, but it can be seen from the resulting values that no averaging would change the conclusions shown; the values are all over or all under the certified values.

TABLE B-1: Values of Mean and Standard Deviation of Assembly Line Type Tests for HC and CO Obtained by Ford for CARB.

Auto	Engine Size	Transmission	No. Tested	HC		CO	
				Mean	S.D.	Mean	S.D.
Maverick	170-IV	Manual	126	1.81	0.30	10.10	7.80
	170-IV	Automatic	84	2.02	0.30	12.11	13.90
	200-IV	Manual	88	1.65	0.31	15.63	9.20
	200-IV	Automatic	203	1.89	0.35	13.44	10.16
F-100	240-IV	Manual	132	1.99	0.66	18.15	22.5
Ford	240-IV	Automatic	31	2.15	0.18	10.85	8.21
Fairlane Montego Mustang	250-IV	Manual	24	1.72	0.26	21.91	12.94
Mustang	250-IV	Automatic	28	1.82	0.28	15.69	6.91
Maverick	250-IV	Automatic	152	1.78	0.30	15.40	11.39
F-100	300-IV	Manual	27	1.57	1.16	16.52	10.72
F-100	300-IV	Automatic	17	1.67	0.37	16.51	9.72
Fairlane Montego Mustang Falcon	302-2V	Automatic	163	1.94	0.51	19.07	10.95
Ford Fairlane	351-2V	Automatic	253	2.18	0.39	20.08	11.02
Cougar Montego Mustang	351-4V	Automatic	19	1.89	1.09	22.52	39.94
F-100	351-4V	Automatic	14	1.56	0.56	17.90	16.91
F-100	360-2V	Manual	77	1.53	0.38	20.54	11.67
Ford	360-2V	Automatic	63	1.70	0.31	15.63	9.02
Ford	390-2V	Automatic	206	2.02	0.36	17.56	6.77
Ford & Mercury	429-2V	Automatic	176	1.98	0.44	16.07	5.44
Lincoln Mark 3	429-4V	Automatic	115	1.79	0.41	16.49	7.37
	460-4V	Automatic	85	2.17	0.47	15.45	10.91

TABLE B-2: Values of Mean and Standard Deviation of Assembly Line Type Tests for HC and CO Obtained by Chrysler for CARB.

Auto	Engine Size	Transmission	A.C. Non-A.C.	No. Tested	HC Mean	HC S.D.	CO Mean	CO S.D.
Barracuda	225	Automatic	---	3	1.71	.342	12.86	6.01
	318		---	2	1.31	.219	8.49	0.28
	318		A.C.	2	1.44	.282	6.84	3.18
	318	Manual	---	1	1.62	-----	7.40	----
	340	Automatic	---	1	1.70	-----	21.9	----
	340		A.C.	1	1.56	-----	18.80	----
	383-2			1	1.41	-----	7.90	----
	383-4			1	1.08	-----	9.50	----
Chrysler	318		---	1	1.24	-----	6.30	----
	383-2		A.C.	15	1.62	.239	13.62	5.20
	383-4			5	1.70	.090	19.72	3.83
	440			17	2.05	.481	17.75	9.83
Dodge	318			2	1.54	.141	8.30	1.27
	383-2			9	1.65	.251	10.36	2.99
	383-4			2	1.53	.021	22.20	7.91
	440			2	1.95	.120	10.40	.14
Challenger	225		---	8	1.69	.357	14.11	4.50
	225	Manual	---	2	1.65	.035	18.60	5.37
	318	Automatic	---	7	1.48	.331	8.69	2.98
	318		A.C.	19	1.42	.234	11.58	4.28
	340			1	1.49	-----	6.70	----
	383-2			9	1.68	.490	12.75	5.36
	383-4		---	3	1.40	.140	10.13	3.18
	383-4		A.C.	5	1.53	.372	19.94	9.76
	383-4	Manual	---	3	1.60	.801	34.3	10.34
	440 HP	Automatic	A.C.	1	1.80	-----	11.20	----
	440-6	Manual	---	1	2.39	-----	26.40	----
Dart	198		---	1	2.49	-----	31.40	----
	225	Automatic	---	26	1.62	.242	16.63	11.64
	225		A.C.	14	1.65	.306	14.13	4.53
	318		---	2	1.43	.049	5.95	1.34
	318		A.C.	25	1.27	.380	8.97	3.81
	340			1	1.63	-----	94.80	----
	340	Manual		1	2.51	-----	11.70	----
Fury	318	Automatic		29	1.65	.455	11.21	4.45
	383-2			12	1.88	.384	17.03	7.02
	383-4			3	1.25	.531	22.16	14.16
	383-4	Manual	---	1	2.12	-----	69.50	----

Auto	Engine Size	Transmission	A.C. Non-A.C.	No. Tested	HC Mean	HC S.D.	CO Mean	CO S.D.
Belvedere	318	Automatic	---	2	1.25	.134	7.60	3.67
	318		A.C.	11	1.40	.282	8.60	1.98
	318	Manual	---	1	1.70	-----	6.40	----
	383-2	Automatic	A.C.	2	1.65	.056	9.24	5.02
	383-4		---	2	1.44	.162	5.45	.35
	383-4		A.C.	2	1.51	.311	21.15	6.29
	383-4	Manual	---	4	1.65	.938	13.75	9.79
	440 HP	Automatic	A.C.	1	1.83	-----	21.20	----
Valiant	198		---	3	2.46	1.091	33.13	38.21
	198	Manual	---	1	1.64	-----	9.80	----
	225	Automatic	---	21	1.69	.179	11.80	5.39
	225		A.C.	7	1.75	.344	15.24	6.83
	225	Manual	---	3	3.99	1.961	11.46	1.00
	225		A.C.	1	2.14	-----	24.60	----
	318	Automatic	---	6	1.74	.559	7.70	2.51
	318		A.C.	5	1.53	.108	10.10	3.36
	318	Manual	---	2	2.12	.593	12.60	7.07
	340	Automatic	---	2	1.73	.0707	9.05	2.75
	340		A.C.	1	2.12	-----	13.00	----
	340	Manual	---	1	3.88	-----	13.90	----
Coronet	318	Automatic	---	2	1.85	.777	8.00	1.83
	318		A.C.	16	1.47	.287	10.46	4.72
	383-2			1	1.73	-----	15.55	----
	383-4			2	1.42	.254	14.05	9.40
	383-4	Manual	---	1	1.02	-----	8.30	----
Charger	318	Automatic	---	2	1.27	.127	12.40	.99
	318		A.C.	3	1.35	.130	13.30	5.13
	383-2			3	1.68	.464	12.16	4.82
	383-4			2	2.01	1.046	36.90	39.03
	440 HP			2	2.04	.339	10.20	2.69
	440 HP	Manual	---	1	2.51	-----	19.30	----
Imperial	460	Automatic	A.C.	2	2.07	.198	14.90	1.55

X. CONCLUSIONS

This study is primarily a preliminary study of the development and implementation of assembly line testing of motor vehicles. Based on information now available, it appears that with the development of a suitable "short" test, assembly line testing could be implemented at a cost of less than $5.00 per vehicle produced or imported. The use of the Federal certification test, rather than the "short" test, would raise costs to around $32.00 per vehicle.

The implementation of assembly testing would appear to require:

1) development of standards, inspection plans, techniques, and a NAPCA staff and organization for monitoring and audit of testing.

The time required for implementation is an estimated 64 months; the staff requirements for monitoring are estimated at 67 persons.

A plan for implementation of assembly-line testing has been developed. According to the plan, the following steps should be taken at once, to meet any projected time schedule for implementation:

1) Obtain agreement on an overall plan for development and implementation and ascertain whether legal questions need be answered,
2) Complete the development of a "short" test with diagnostic potential; determine its correlation with Federal test procedures; prepare statistical inspection procedures under which it could be applied,
3) Study the relations between green-engine tests and 4000-mile or other standard mileage tests of Federal tests. By statistical analysis,

compile suitable corresponding relations between standards for Federal tests and green-engine tests.

4) Develop detailed sampling plans for assembly line and foreign vehicle testing.

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